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Post-Mining Groundwater Supply At The Battle Site: Plains Hydrology and Reclamation Project

Heritage Fund

Alberta
LAND CONSERVATION AND
RECLAMATION COUNCIL
Reclamation Research
Technical Advisory Committee

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Report #
RRTAC 86-6

POST-MINING GROUNDWATER SUPPLY AT THE BATTLE RIVER SITE: PLAINS HYDROLOGY AND RECLAMATION PROJECT

by

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Reclamation Council

1986

STATEMENT OF OBJECTIVE

The recommendations and conclusions in this report are those of the authors and not those of the Alberta Government or its representatives.

This report is intended to provide Government and Industry staff with up to date technical information to assist in the development of guidelines and operating procedures. The report is also available to the Public so that interested individuals similarly have access to the best available information on land reclamation topics.

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ALBERTA'S RECLAMATION RESEARCH PROGRAM

The regulation of surface disturbances in Alberta is the responsibility of the Land Conservation and Reclamation Council. The Council executive consists of a chairman from the Department of the Environment and two deputy chairman from the Department of Forestry, Lands & Wildlife. Among other functions, the Council oversees programs for reclamation of abandoned disturbances and reclamation research. The reclamation research program was established to provide answers to the many practical questions which arise in reclamation. Funds for implementing both the operational and research programs are drawn from Alberta's Heritage Savings Trust Fund.

To assist in technical matters related to the development and administration of the research program the Council appointed the Reclamation Research Technical Advisory Committee (RRTAC). The Committee first met in March, 1978 and consists of eight members representing the Alberta Departments of Agriculture, Energy, Forestry, Lands & Wildlife, Environment and the Alberta Research Council. The Committee meets regularly to update research priorities, review solicited and unsolicited research proposals, arrange workshops and otherwise act as a referral and coordinating body for Reclamation Research.

Additional information on the Reclamation Research Program may be obtained by contacting:

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PREFACE

This is one of a series of reports that presents the findings of the Plains Hydrology and Reclamation Projects (PHRP), an interdisciplinary study that focuses primarily on hydrologic aspects of the reclamation of surface coal mines in the plains of Alberta. This research has been conducted by the Alberta Research Council, as part of the Alberta Government's Reclamation Research Program. The program is managed by the Land Conservation and Reclamation Council and is supported by the Heritage Trust Fund.

The focus of the PHRP is to develop a predictive framework that will permit projection of success for reclamation and impact of mining on water resources on a long-term basis. The predictive framework is based on an understanding of processes acting within the landscape so that, in the future, mine sites that are not totally analogous to those that have been studied can be evaluated as well.

The project involves a holistic approach to reclamation by integration of studies of geology, hydrogeology, and soils, not only in the proposed mining area, but also in the adjoining unmined areas. This approach permits the assessment of impacts and of long-term performance, not only in reclaimed areas, but also in the surrounding area.

The research of the PHRP was directed toward the following two major objectives and eight subobjectives.

Objective A

To evaluate the potential for reclamation of lands to be surface mined. The focus is on features of the landscape that make it productive in a broad sense not restricted to revegetation. This objective was organized into five subobjectives.

1. To assess and evaluate the potential for long-term degradation of reclaimed soils through salt build-up.
2. To assess and evaluate the effectiveness of topographic modification and selective placement of materials to

mitigate deleterious impacts on chemical quality of groundwater.

3. To assess the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations.
4. To evaluate the productivity potential (capability) of post-mining landscapes and the significance of changes in capability as a result of mining.
5. To assess and evaluate limitations to post-mining land use posed by physical instability of cast overburden.

Objective B

To evaluate the long-term impact of mining and reclamation on water quantity and quality. This objective was organized into three subobjectives.

1. To assess and evaluate the long-term alteration of quality of groundwater in cast overburden and surface water fed from mine spoil as a result of the generation of weathering products.
2. To assess and evaluate infiltration, groundwater recharge, and groundwater-surface water interactions within cast overburden.
3. To characterize the groundwater chemistry generated within cast overburden.

Studies directed at these objectives began in 1979 at the Battle River site in east-central Alberta. Work began in 1982 at a second study area at Highvale Mine south of Lake Wabamun. Significant progress had been made on all project objectives by the end of the first phase of study in March 1984. This present series of reports summarizes the state of our knowledge at the end of this phase of study. Work is now continuing on the Phase II objectives to gain an even greater understanding of the complex physical and chemical processes in reclaimed landscapes.

The following report deals with studies directed at Subobjective A-3: To assess the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The focus of this report, implicit in the above statement of objective, is the assessment of post-mining groundwater supply; the post-mining land use is assumed to be essentially the same as the pre-mining use, that is, primarily agricultural with single-family rural residences, with a minor component of wild-land. This report presents the results of the PHRP for the Battle River Mining area. It includes a characterization of the existing, or pre-mining, groundwater supply, and an evaluation of five potential post-mining aquifers, four of which are sandstone units situated below the base of mining. In the eastern part of the study area a sandstone unit within the Bearpaw Formation, referred to as the "Deep Sandstone Aquifer" is the post-mining aquifer of choice. In portions of the western part of the study area there is no suitable post-mining aquifer, primarily because the water quality from sandstone in the Bearpaw Formation is too poor.

ABSTRACT

Mining in the Battle River study area will remove the Paintearth and Battle River Coal Beds, the two most productive aquifers currently supplying local water supply demands. In the eastern part of the mine area, approximately east of Highway 855, the "Deep Sandstone aquifer", a sandstone bed located about 60 m beneath the Battle River Bed, is capable of producing adequate amounts of water with sufficiently high chemical quality to meet domestic and stock watering needs of individual forms. In the western part of the mine area, water in the Deep Sandstone aquifer is of degraded quality and is too saline for human consumption and only marginally acceptable for stock watering. No other suitable replacement water supply was found in the western part of the proposed mining area although four sandstone units beneath the Battle River Bed were evaluated. No coarse-grained sediment that could be developed to support a distribution system was found in the fill of the Battle River or Paintearth Creek. The mine spoil itself is too impermeable to produce enough water and the chemical quality of the water in the spoil is unacceptable for human or livestock consumption.

The only groundwater supply option for domestic purposes in the western part of the study area is the unmined coal of the Paintearth and Battle River Beds beyond the limits of mining. Development of these aquifers must take into account at least partial dewatering within 1 to 3 km of the highwall during active mining. In addition, the same zone will be subject to potential invasion by low quality spoil-derived groundwater following completion of mining.

ACKNOWLEDGEMENTS

This project was sponsored by the Reclamation Research Technical Advisory Committee of the Alberta Land Conservation and Reclamation Council, with financial support from the Alberta Heritage Trust Fund. Alberta Power Limited, Luscar Limited, and Manalta Coal Limited, all aided the study by providing both available data and access to lands for the research work.

1. INTRODUCTION

The surface mining of coal in the Battle River Project area will ultimately disrupt approximately 60 km^2 of agricultural land. Accompanying this disturbance is the loss of two significant aquifers, both of which are coal beds within the Horseshoe Canyon Formation. Concern for the long-term viability of the post-mining landscape, including the need for an evaluation of post-mining water supply potential, resulted in a study of the area by the Alberta Research Council under the auspices of the Plains Hydrology and Reclamation Project (PHRP).

The objective of this study was to assess the availability of water supply in or beneath cast overburden to support post-mining land use, taking into account both quantity and quality. It became clear in the very early stages of the investigation that groundwater within the spoil at the Battle River site was unsuitable for exploitation because of very poor water quality (typically 4000 to 8000 mg/L TDS) combined with the generally low transmissivity of the spoil material (Trudell and Moran 1982). The major focus of the study, then, was on aquifers located stratigraphically below the lowermost mineable coal seam.

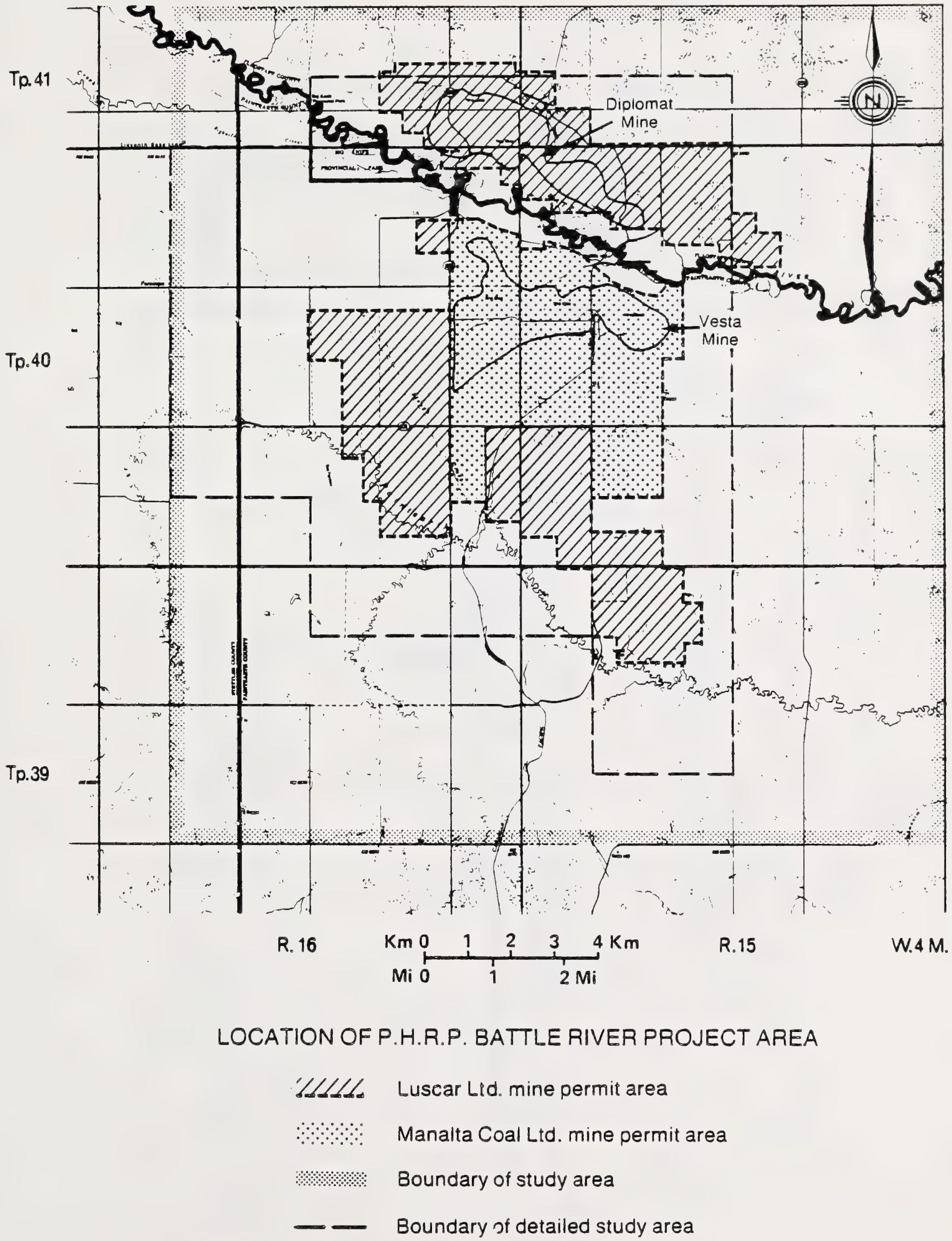
The following report describes the characteristics of the existing domestic water wells and coal aquifers as the pre-mining water supply, followed by an analysis of five potential post-mining aquifers.

2. SITE DESCRIPTION

The Battle River study area is located approximately 200 km southeast of Edmonton, Alberta, in the Interior Plains Physiographic Province. The land is flat to gently rolling, and the regional topographic slope is to the northeast. The vertical decline in land surface elevation from the southwest part of the study area to the northeast is approximately 100 m.

The principal topographic features of the area are the deeply-incised valleys of the Battle River and Paintearth Creek (Figure 1). The Battle River flows in a valley that is approximately 1 km wide and is eroded 60 m below the level of the surrounding countryside. In addition, the valley is filled to approximately 75 m below river level with unconsolidated sand, silt, and clay of Quaternary age. The valley of Paintearth Creek is shallow with bedrock only a few metres below creek level in the western part of the study area. In the southeast part of the study area, the Paintearth Creek Valley is approximately 30 m below the level of the surrounding landscape, and is filled with sediment of Quaternary age to a depth of approximately 30 m below stream level. The aquifers and aquitards of the Battle River area occur within the late Cretaceous Horseshoe Canyon and Bearpaw Formations (Maslowski Schutze et al. 1985), as shown in a generalized stratigraphic column (Figure 2) and hydrogeologic cross section for the area (Figure 3). Two laterally continuous coal seams within the Horseshoe Canyon Formation, the Battle River Bed and the Paintearth Bed, are important aquifers. The Paintearth Bed is the shallowest aquifer in the study area and is separated from the underlying Battle River Bed by a sequence of interbedded shale, siltstone and sandstone that acts as an aquitard. A layer of shale, ranging from 0 to 5 m thick, separates the Battle River Bed from the underlying Delta Sandstone, a fine-grained, montmorillonitic sandstone that is a very poor aquifer.

Three sandstone aquifers occur within the Bearpaw Formation, below the Delta Sandstone (Figures 2 and 3). These aquifers are referred to, from shallowest to deepest, as the Middle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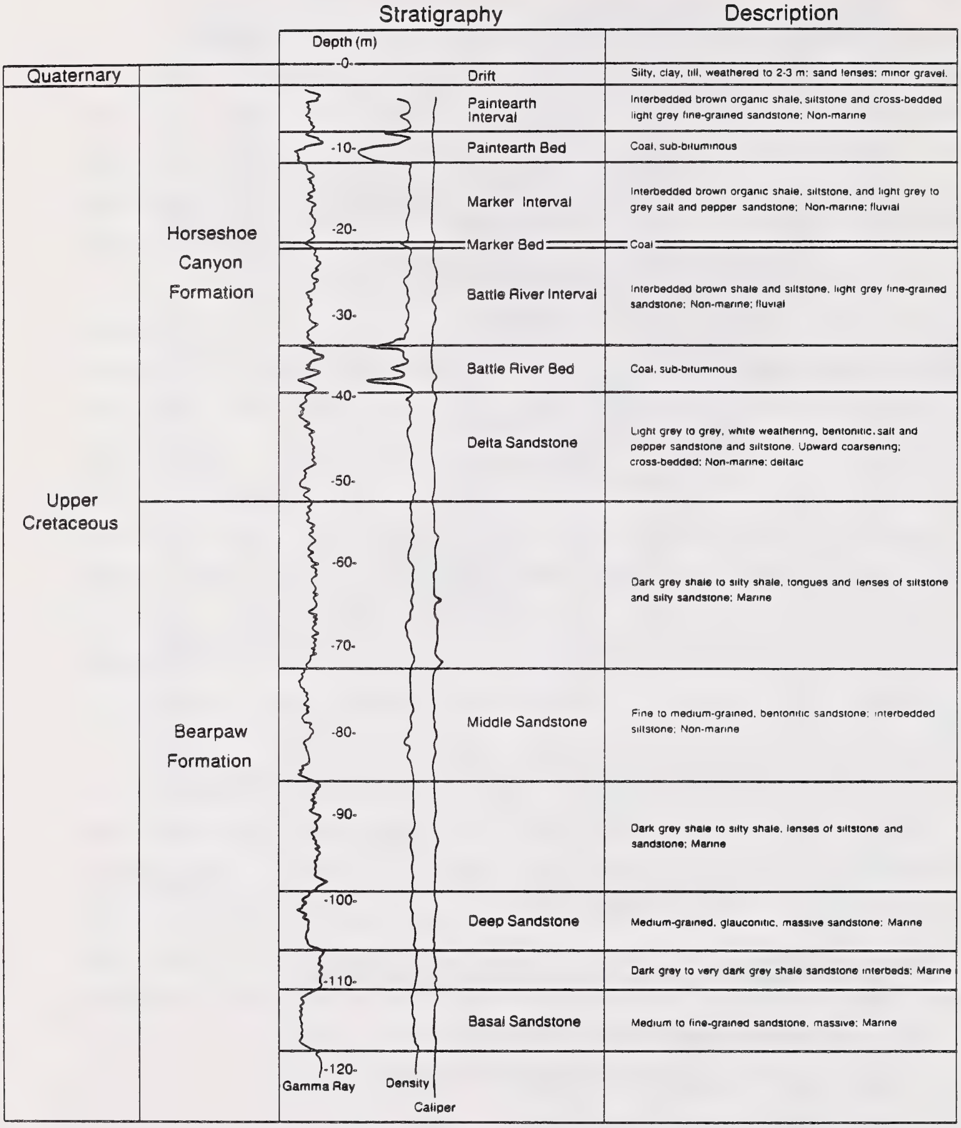
LOCATION OF P.H.R.P. BATTLE RIVER PROJECT AREA
Luscar Ltd. mine permit area
Manalta Coal Ltd. mine permit area
Boundary of study area
Boundary of detailed study area

Figure 1. Location of the Battle River study area.



		Stratigraphy	Description
Quaternary		Drift	Silty, clay, till, weathered to 2-3 m: sand lenses: minor gravel.
Upper Cretaceous	Horseshoe Canyon Formation	Paintearth Interval	Interbedded brown organic shale, siltstone and cross-bedded light grey fine-grained sandstone: Non-marine
		Paintearth Bed	Coal, sub-bituminous
		Marker Interval	Interbedded brown organic shale, siltstone, and light grey to grey salt and pepper sandstone: Non-marine: fluvial
		Marker Bed	Coal
		Battle River Interval	Interbedded brown shale and siltstone, light grey fine-grained sandstone: Non-marine: fluvial
		Battle River Bed	Coal, sub-bituminous
		Delta Sandstone	Light grey to grey, white weathering, bentonitic, salt and pepper sandstone and siltstone. Upward coarsening: cross-bedded: Non-marine: deltaic
	Bearpaw Formation		Dark grey shale to silty shale, tongues and lenses of siltstone and silty sandstone: Marine
		Middle Sandstone	Fine to medium-grained, bentonitic sandstone: interbedded siltstone: Non-marine
			Dark grey shale to silty shale, lenses of siltstone and sandstone: Marine
		Deep Sandstone	Medium-grained, glauconitic, massive sandstone: Marine
			Dark grey to very dark grey shale sandstone interbeds: Marine
		Basal Sandstone	Medium to fine-grained sandstone, massive: Marine

Figure 2. Generalized stratigraphic column for the Battle River study area.

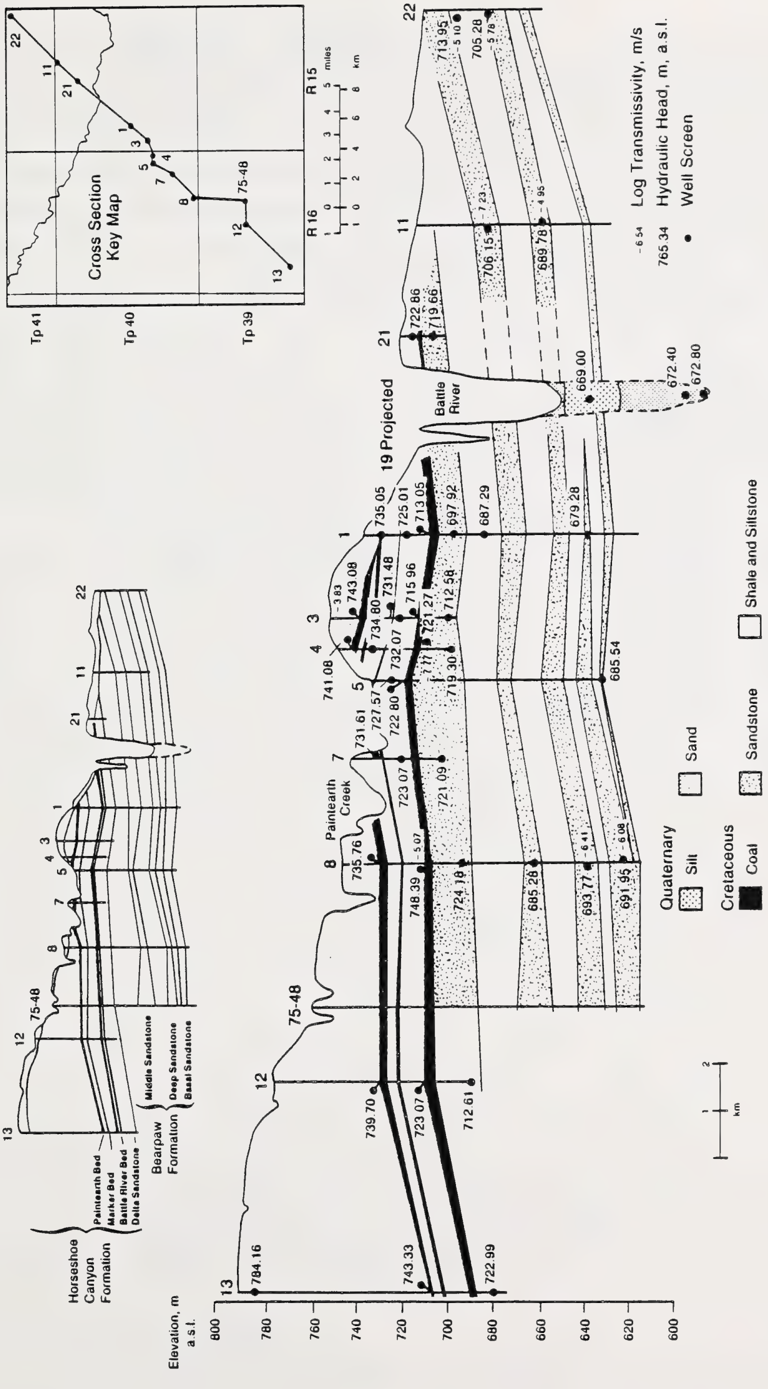


Figure 3. Southwest-northeast hydrogeologic cross section A-A' for the Battle River study area.

Sandstone, Deep Sandstone, and Basal Sandstone. The Deep and Basal Sandstone aquifers are laterally continuous across the study area, whereas the Middle Sandstone is present in the western part of the area, but grades laterally into siltstone in the part of the study area east of Highway 855. These aquifers are separated from each other by aquitards composed predominantly of shale.

The Battle River Bed and Paintearth Bed aquifers presently supply water for 21 of the domestic wells (61%) in the Battle River area. These aquifers will be disrupted by mining over a significant area; therefore, for the purposes of comparison, they will be treated as a pre-mining water supply source for the area. However, in parts of the study area beyond the limit of mining these aquifers will remain intact and may be suitable for utilization after mining.

3. METHODS OF INVESTIGATION

The instrumentation utilized in this investigation included 188 piezometers and 3 production wells at 38 sites. The piezometers were constructed of 5.1 cm diameter PVC pipe with a section of machine-slotted (0.51 mm) PVC pipe for the intake zone. The completion included a pack of 10 to 20 or 12 to 20 mesh rounded silica sand, and a cement grout to ground surface. Many of the piezometers less than 50 m in depth also utilized a 1.2 m bentonite seal between the sand pack and grout. In those piezometers without a bentonite seal, the sand pack was extended approximately 3 m above the top of the screen to allow for penetration of the grout into the sand without influencing the intake zone.

The hydraulic properties of aquifers were determined primarily by single well response testing of piezometers (Hvorslev 1951; Cooper et al. 1967). The transmissivities determined from these tests were then used in conjunction with available drawdown data based on static water level measurements to calculate an approximate long-term well yield (Q) for the aquifer tested. This analysis was done using the equations of Cooper and Jacob (1946).

Water samples were collected from domestic water wells and piezometers, and analysed for major and minor ionic constituents. The species analysed were calcium, magnesium, sodium, potassium, sulfate, chloride, carbonate, bicarbonate, nitrate, fluoride, and silica. In addition, pH, specific conductance and total dissolved solids (TDS) were determined. Water samples were collected from piezometers primarily by means of a bailer. These samples were filtered through a 0.45 micron membrane filter, and pH, specific conductance, total iron, H_2S and alkalinity measured in the field. All other determinations were done at the Chemistry Analytical Laboratory, Alberta Research Council.

3.1 DATA SYNTHESIS

In order to evaluate differences in water quality between aquifers it is necessary to characterize the water quality within an aquifer, based on the chemical analysis of water samples. This characterization is complicated by the fact that standard statistical treatments of data, based on various theoretical distributions, are not readily adaptable to the comparison of water quality data between aquifers because the type and shape of the sample distributions tend to vary between aquifers, for a given parameter, as well as from one parameter to another. The problem is further complicated by the large variation in the number of available samples from one aquifer to another. This is not to say that such comparisons cannot be handled by somewhat more sophisticated statistical analysis; however, it is desirable to apply an analytical technique that is simple, if less rigorous, and lends itself to ready comprehension by a relatively broad audience. In addition, the method should provide a characterization of the desired data without relying on inherent assumptions concerning the nature of the distribution.

The method that is applied in this report is based on the characteristics of the cumulative frequency distribution curve for the sample group from each aquifer, examples of which are illustrated in Figure 4. This approach allows the similarities or differences in water quality parameters between aquifers to be described, and makes it possible to describe the range of concentrations within which one aquifer is preferable to another.

For example, Figure 4 is a plot of the cumulative frequency distributions of concentration (of any given ionic species) for two hypothetical aquifers, A and B. In this example, the class size is 20 mg/L, so that the first class is from 0 to 20 mg/L, the second is from 21 to 40 mg/L, and so on. Examining the curves at the hypothetical maximum allowable concentration of 160 mg/L, for instance, it can be seen that 75% of the samples from aquifer A have a concentration less than 160 mg/L; similarly, 60% of the samples from aquifer B have a concentration of less than 160 mg/L. Clearly, from a water quality standpoint, this suggests that aquifer A is more desirable than B. At concentrations above 160 mg/L the difference between the two aquifers becomes even more pronounced. One hundred

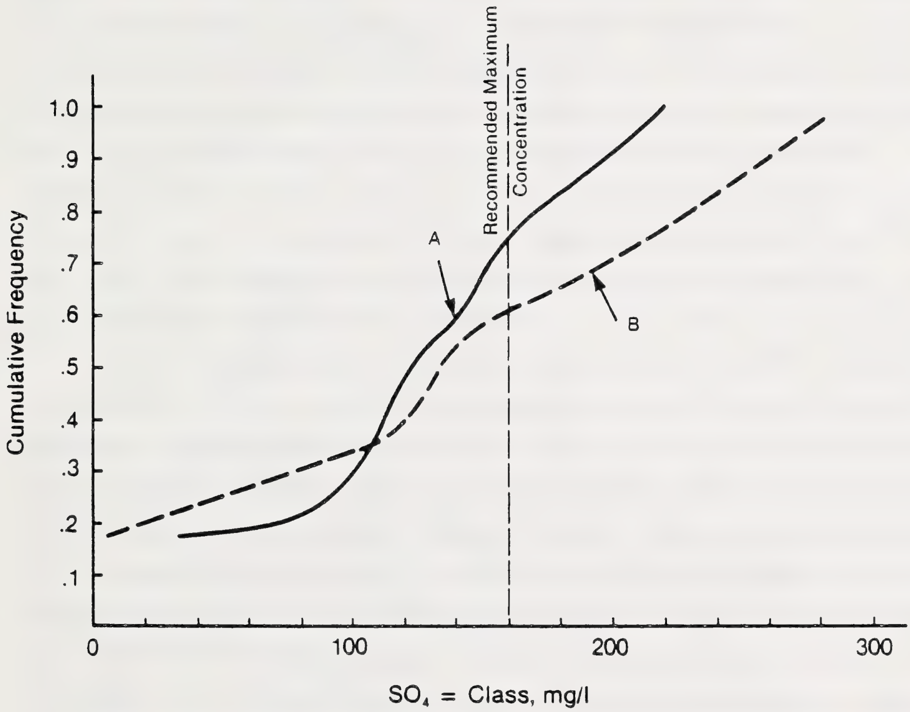


Figure 4. Example cumulative frequency distributions for two groups of water samples, A and B.

percent of the samples from A have concentrations less than 220 mg/L, whereas only 75% of the samples from B have less than 220 mg/L. At concentrations below 160 mg/L the difference between aquifers is less pronounced; 35% of samples from both A and B have concentrations less than 110 mg/L (the point at which the two curves cross). Below 110 mg/L, aquifer B tends to be of somewhat better quality than A. Overall, however, considering particularly the percentage of samples having less than the maximum allowable concentration, aquifer A clearly has the better water quality of the two.

The evaluation of the water quality of potential post-mining water supplies is approached in this report from two distinct but related directions. First, potential post-mining aquifers are compared to pre-mining domestic water wells in order to evaluate the suitability of the alternate supply to meet the standard of the existing supply. The second direction addresses a more fundamental question: the extent to which the groundwater resource will be diminished as a result of mining. To address this question, post-mining aquifer properties are also compared to a standard based on the pre-mining coal aquifers which, at the Battle River site, represent the groundwater resource lost due to the mining process. In this manner it may be possible to determine if the groundwater resource that remains after mining represents a degeneration or improvement over the lost coal aquifers.

The dissolved constituents considered in this report to best represent the suitability of a water supply for domestic consumption are total dissolved solids and sulfate, although iron and sulfide are also evaluated in many cases because of their highly disagreeable characteristics. The maximum acceptable concentration of total dissolved solids in water for human consumption, based on aesthetic as opposed to health-related concerns, is 500 mg/L (Canada Department of National Health and Welfare 1979). Since this standard is very seldom met in groundwater from the prairies, it is of little utility in evaluating post-mining water supply. Water above 2000 mg/L in total dissolved solids has a laxative effect on humans, whereas concentrations up to 3000 mg/L are considered suitable for livestock (McNeely et al. 1979). Even these levels should be considered as approximate, as locally consumers may be accustomed to water with somewhat higher TDS concentrations. Sulfate is also a useful constituent in evaluating water quality for domestic use. At concentrations between 150 and 500 mg/L sulfate can have a laxative effect on humans; above 500 mg/L it imparts a bitter taste to water and can cause catharsis and gastro-intestinal irritation (McNeely et al. 1979). The objective concentration of sulfate for drinking water is 150 mg/L (Canada Department of National Health and Welfare 1979) although an objective concentration of 250 mg/L has been proposed (McNeely et al. 1979).

The question of water quantity (or well yield) associated with both existing and replacement water supply is addressed on the basis of adequate/inadequate yield. For the purpose of domestic water supply a yield of 0.1 L/s (including a factor of safety associated with the potential inaccuracy of short term pumping or single-well response tests) is considered to be the minimum required (Trudell and Moran 1985). All domestic wells were assumed to meet this criterion, since they are utilized for domestic supply. Potential post-mining supplies were either accepted (yield $\geqslant$ 0.1 L/s) or rejected (yield $\leqslant$ 0.1 L/s) based on this criterion.

4. EXISTING WATER SUPPLY

There are 34 domestic water wells within the Battle River study area, as illustrated in Figure 5. Of these wells, 61% are completed in coal beds; 29% in the Battle River Bed and 32% in the Paintearth Bed. Of the remaining 29%, 20% are completed in the sandstone beds of the Bearpaw Formation, located stratigraphically below the deepest mineable coal. A discussion of the characteristics of these deeper sandstone aquifers is presented in the section entitled "Post-mining Water Supply". Six domestic wells are located within the 30-year mine permit area, three of which are completed in the Paintearth Bed, with the remaining three completed in the sandstone beds of the Bearpaw Formation.

Domestic wells provide a good representation of the quality of water that is presently enjoyed by the local population, and form the standard against which any alternate water supply will be judged. A cumulative frequency distribution diagram of total dissolved solids for domestic wells in the Battle River area (Figure 6) shows that 65% produce water with less than the recommended limit of 2000 mg/L TDS, whereas 20% produce very fresh water (less than 1000 mg/L), and 20% produce slightly brackish water (greater than the 3000 mg/L limit for livestock, Table 1). Only 3% of the domestic wells produce water with less than the 500 mg/L TDS standard. The mean total dissolved solids concentration is 2252 mg/L, with a standard deviation of 1571 mg/L. Only 60% of the domestic wells produce water with a sulfate concentration less than the recommended maximum of 500 mg/L with 39% less than the 150 mg/L standard, as illustrated in Figure 7. Of the wells with greater than 500 mg/L sulfate, half (20%) have concentrations between 500 and 1300 mg/L, whereas the final half consists of wells with sulfate concentrations ranging from 2000 to 4000 mg/L. The mean sulfate concentration for domestic wells is 820 mg/L, with a standard deviation of 1123 mg/L. The vertical distribution by aquifer of total dissolved solids and sulfate, from domestic wells in the Battle River area is illustrated in Figure 8.

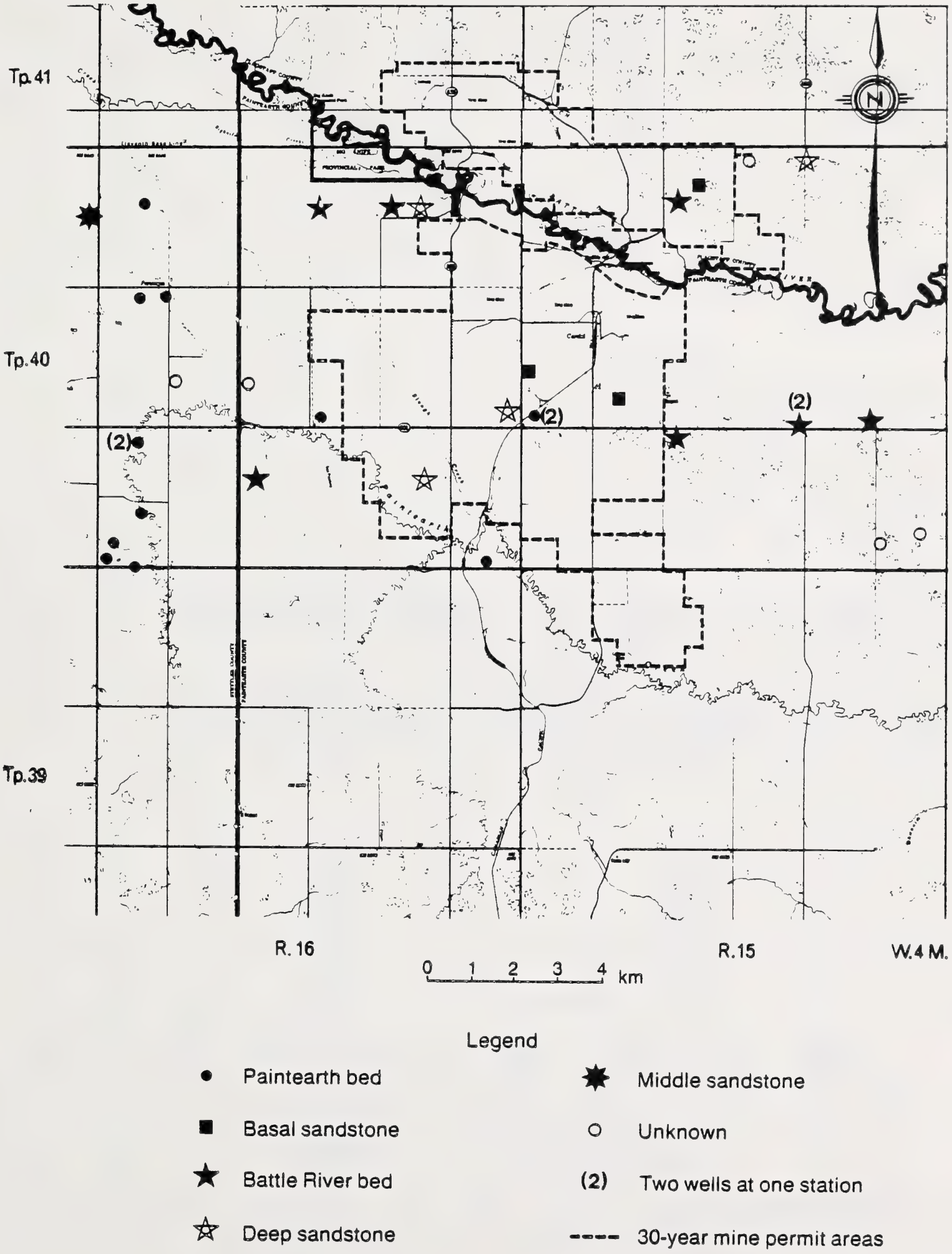


Figure 5. Location of domestic wells, by stratigraphic unit, in the Battle River study area.

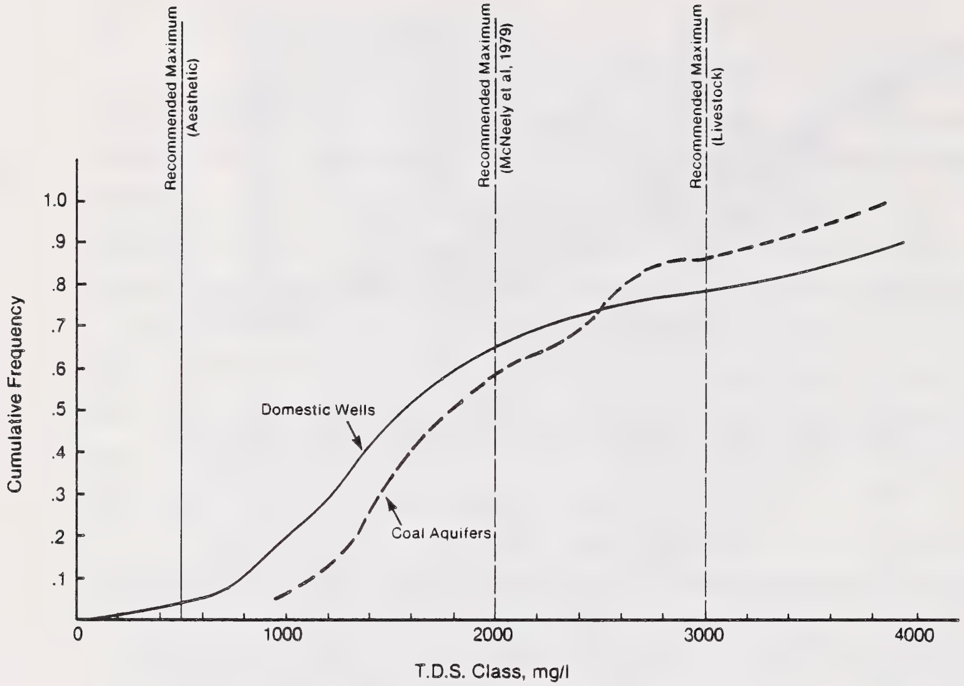


Figure 6. Cumulative frequency distribution for total dissolved solids (TDS) in domestic water wells and coal aquifers.

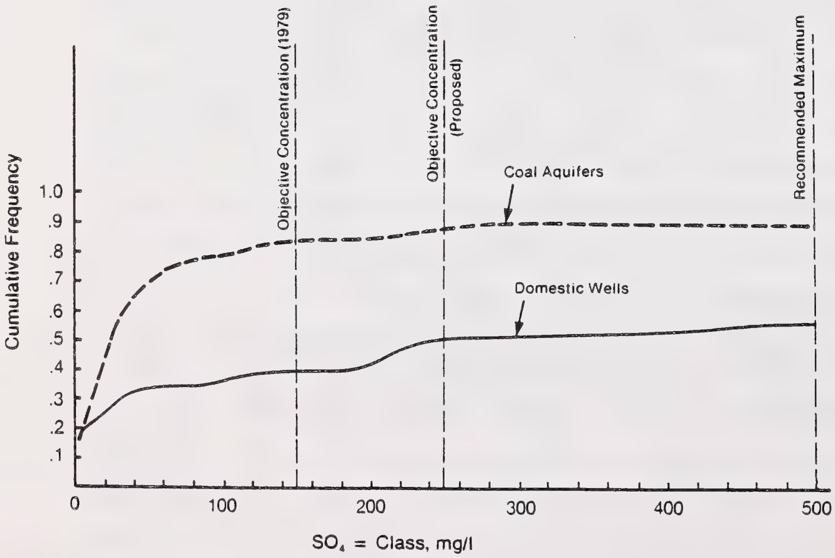


Figure 7. Cumulative frequency distribution for sulfate in domestic water wells and coal aquifers.

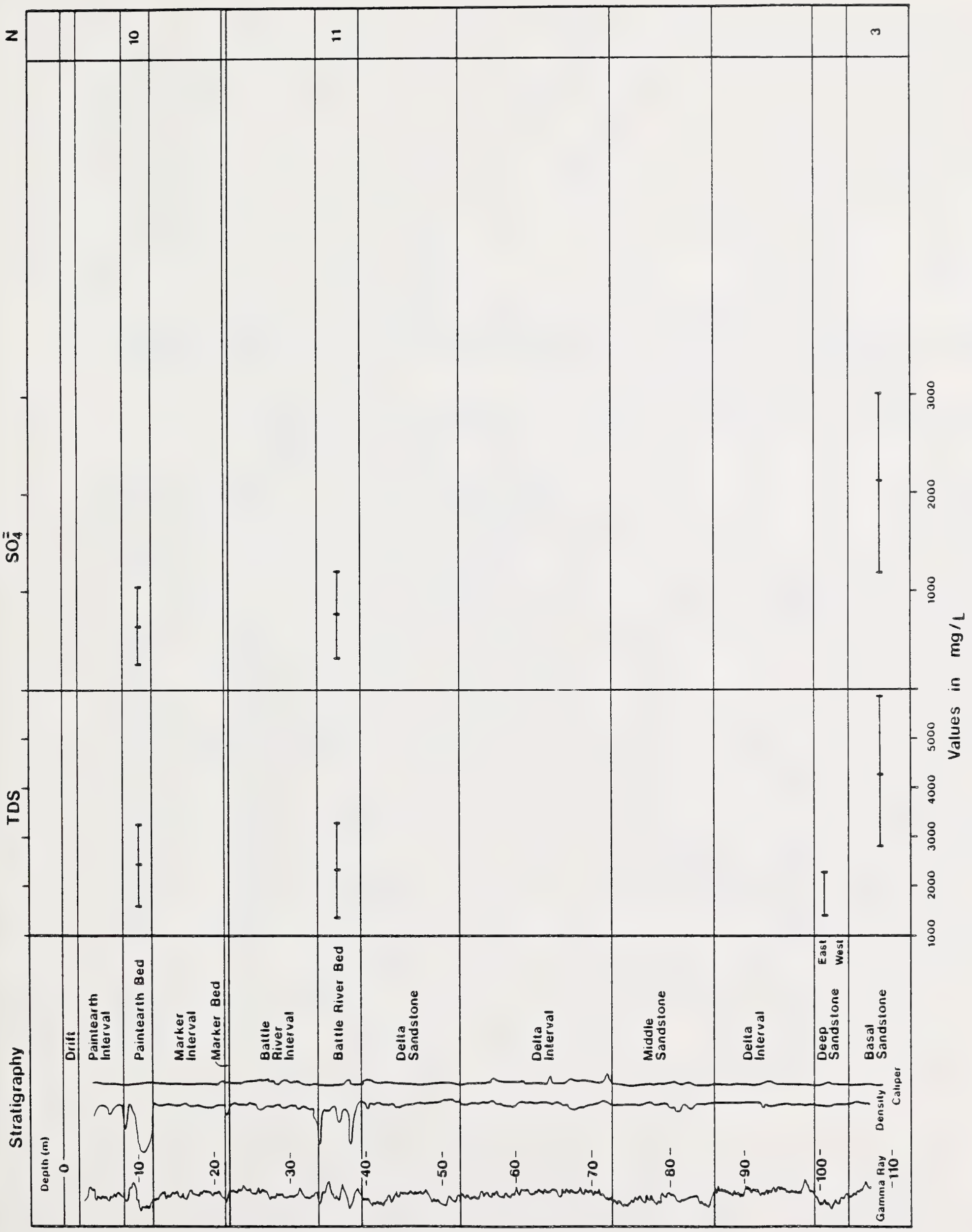


Figure 8. Standard deviation (spread of bars), and mean (centre of bar) for total dissolved solids and sulfate from domestic wells in Battle River area.

Table 1. Summary of water quality distribution for the pre-mining standards (domestic wells and coal aquifers) and potential post-mining aquifers.

	PERCENTAGE OF SAMPLES				
	TDS (mg/L)			$SO_4^=$ (mg/L)	
	<500	<2000	<3000	<150	<500
Pre-Mining Standards					
Domestic Wells	3	65	78	39	60
Coal Aquifers	-	59	86	83	89
Post-Mining Aquifers					
Delta Sandstone	0	67	97	85	85
Deep Sandstone West Group	0	-	52	80	80
Deep Sandstone East Group	0	71	100	80	83
Middle Sandstone	0	40	83	75	75

Since the post-mining aquifer will be, in a great many cases, replacing the Battle River Bed and Paintearth Bed aquifers, a comparison of water quality between potential post-mining aquifers and the two coal aquifers is also made. This comparison helps to avoid some of the uncertainties associated with domestic well water samples, and also provides an estimate of the real change in groundwater resource potential as a result of the mining. Analyses of water samples from PHRP piezometers completed in the Battle River Bed and Paintearth Bed provide the basis for this comparison, as illustrated in Figures 6 and 7 and summarized in Table 1.

Comparison of the two curves illustrated in Figure 6 shows that, below 2500 mg/L total dissolved solids, the water quality in the coal aquifers (Battle River Bed and Paintearth Bed) is similar to, but not quite as good as the water quality from domestic wells. For example, 65% of the domestic wells produce water with less than 2000 mg/L TDS, whereas only 59% of samples from the coal aquifers have TDS concentrations less than 2000 mg/L. For the fraction of samples with TDS concentrations above 2500 mg/L, the coal aquifers tend to be somewhat less saline than the corresponding group of domestic wells. For sulfate concentrations (Figure 7) the coal aquifers are far superior to domestic wells as a whole. For example, 83% of samples from the coal aquifers have less than 150 mg/L sulfate, whereas only 39% of the domestic well samples are below this level. This indicates that, in terms of sulfate concentrations, the coal aquifer samples represent a more stringent standard for comparison than do domestic well samples. For total dissolved solids, on the other hand, the two groups represent a comparable standard, within 10%.

The characteristics of the individual coal aquifers (Paintearth Bed and Battle River Bed) are also evaluated below.

4.1 PAINTEARTH BED AQUIFER

The Paintearth Bed is continuous over most of the western part of the study area. East of Highway 855, it occurs as a large outlier approximately 18 km2 in area, that either outcrops or subcrops within the study area (Figure 9). The coal is generally 3 to 4 m thick in the south-central part of the study area, where it is split into two seams separated by a 0.3 m shale parting. In the western part of the study area the coal is approximately 2 m thick, and split into more than two seams with greater than 50% partings (Maslowski Schutze et al. 1985).

Water from the Paintearth Bed is either of sodium-bicarbonate-sulfate type or sodium-calcium-sulfate type. The mean total dissolved solids concentration of water from domestic wells completed in the Paintearth Bed is 2456 mg/L, with a standard deviation of 1688 mg/L; the range of TDS values is from 1520 to 6540 mg/L. On the basis of water samples from PHRP piezometers in this unit the mean TDS concentration is 3154 mg/L, with a standard deviation of 2666 mg/L, and with individual values ranging from 1291 to 12512 mg/L (Figure 9). Mean sulfide and iron concentrations in the Paintearth Bed aquifer, at 0.010 mg/L and 0.057 mg/L respectively, are within recommended limits. Sulfate, however, with a mean value of 1064 mg/L, is more than double the recommended limit of 500 mg/L. The mean value in this case is somewhat less than representative, as only a small number of wells are over the recommended limit for sulfate, but those that are over exceed the limit by a large margin, as indicated by the standard deviation of 1981 mg/L. The range of values for sulfate is from 9.0 to 7880 mg/L (Figure 9). A total of 5 wells of 13 tested in the Paintearth Bed were over the accepted limit of 500 mg/L. These well sites circumscribe a rough arc, from BR-25, (located at the southeast corner of Vesta Mine), extending through BR-46, BR-4, and BR-9. BR-8, located 2 m south of BR-9 also has a level of sulfate over 500 mg/L. The sites where high sulfate concentrations are present tend to occur within 1 km of the coal subcrop, where the Paintearth Bed is overlain by thin cover, mainly drift.

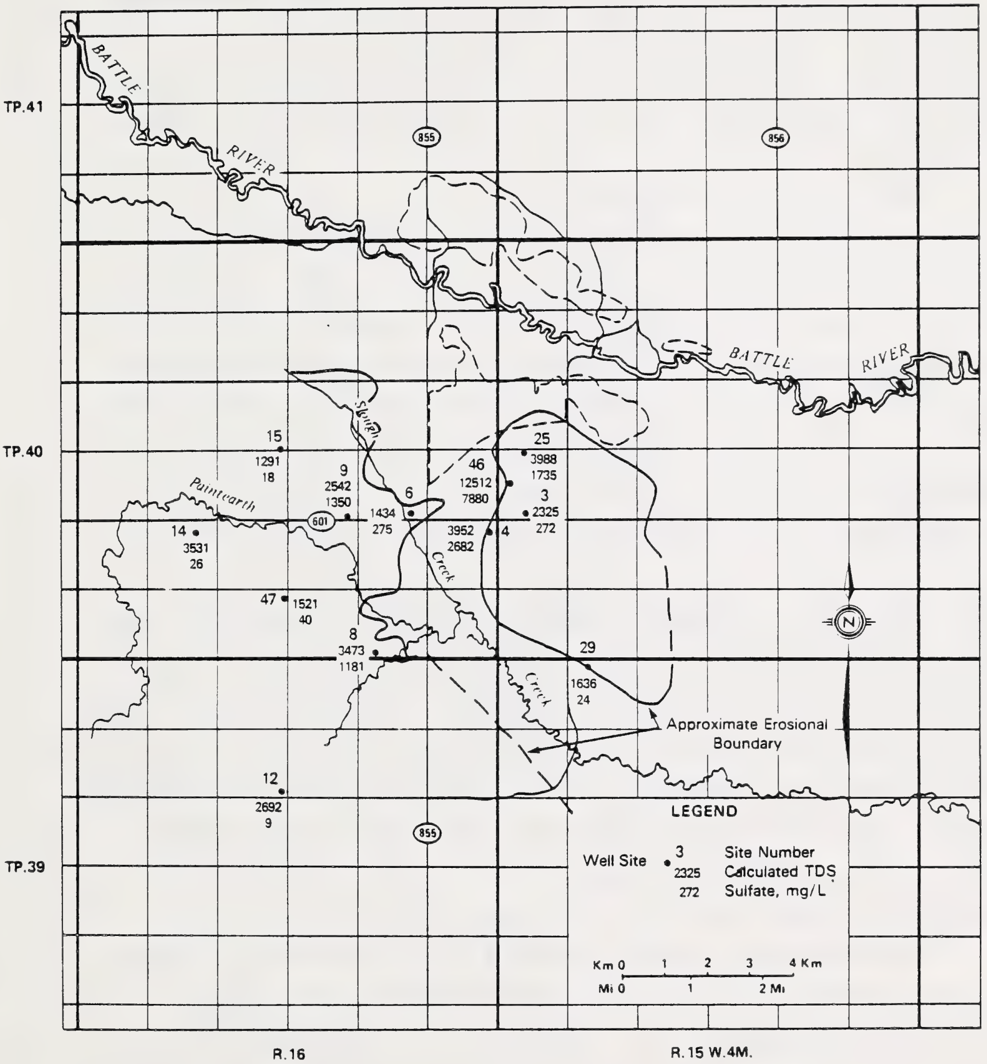


Figure 9. Concentration of total dissolved solids (TDS) and sulfate in the Paintearth Bed aquifer.

The mean transmissivity of the Paintearth Bed, determined from 5 single well response tests on 5 piezometers is 1.51×10^{-5} m^2/s (Figure 10). This corresponds to a mean calculated well yield of 0.22 L/s, which is adequate for domestic supply needs.

4.2 BATTLE RIVER BED AQUIFER

The Battle River Bed aquifer is continuous over the project area, except in stream valleys where it has been eroded. The coal ranges in thickness from 2.5 to 3.5 m, and is commonly split into two or more seams separated by thin shale partings, particularly in the western part of the study area (Maslowski Schutze et al. 1985). The Battle River Bed generally lies less than 40 m below ground surface, but increases in depth towards the south and west as the result of rising land surface elevation and the southwesterly dip of the coal bed.

The chemical makeup of water in the Battle River Bed ranges from sodium-bicarbonate to sodium-chloride. The salinity is lower and less variable than in the Paintearth Bed. Domestic wells in the Battle River Bed have a mean TDS concentration of 1815 mg/L, with a standard deviation of 1003 mg/L. Water samples from PHRP piezometers completed in the Battle River Bed have a mean TDS concentration of 1895 mg/L, with a standard deviation of 649 mg/L. Individual TDS concentrations range from 925 to 4234 mg/L.

The best water quality from the Battle River Bed is found in the part of the study area west of Highway 855, where total dissolved solids are generally in the range of 1200 to 2100 mg/L (Figure 11). An exception to this is an area extending approximately 1 km west of Vesta Mine through sites BR-10 and BR-75, where total dissolved solids are 4334 and 2515 respectively, reflecting migration of spoil groundwater from Vesta Mine into the unmined coal (Trudell and Moran 1982, 1984, in press). In the southeast portion of the study area, north of Paintearth Creek, total dissolved solids range from 2500 to 3500 mg/L and represent the poorest quality water from this aquifer. Sulfate, with a mean concentration of 41.9 mg/L,

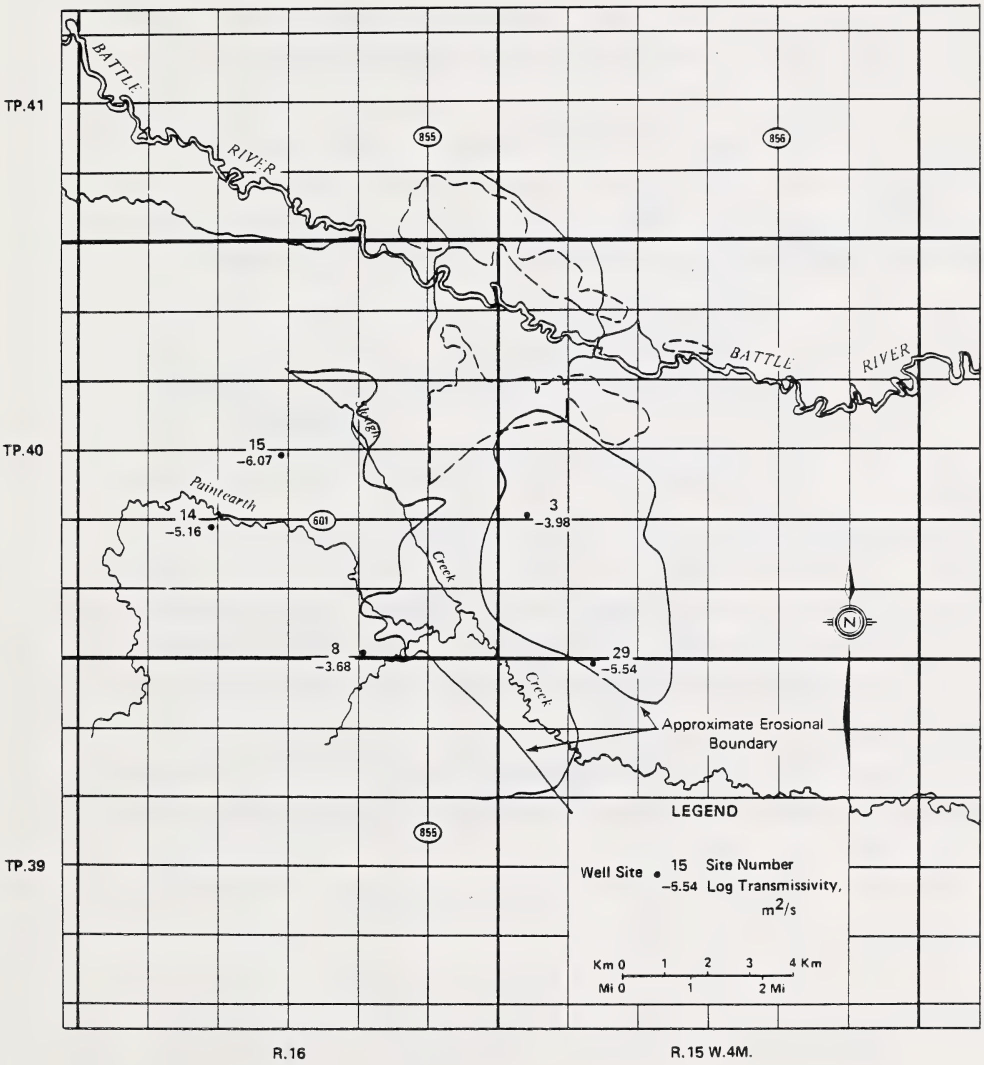


Figure 10. Log transmissivity (m^2/s) for the Paintearth Bed aquifer.

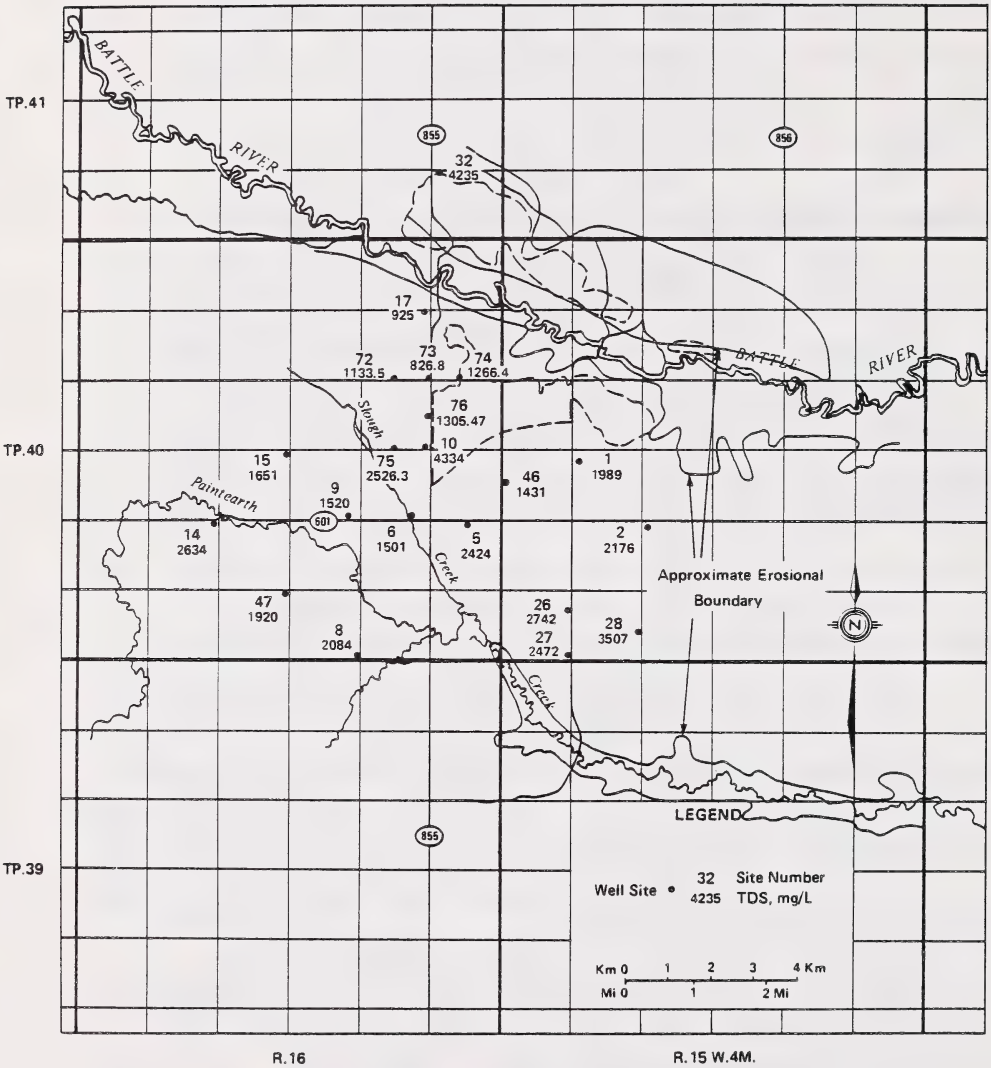


Figure 11. Total dissolved solids concentration (mg/L) in the Battle River Bed aquifer.

is well within the recommended maximum for domestic consumption, as are sulfide and iron at 0.043 mg/L and 0.093 mg/L respectively.

The mean transmissivity of the Battle River Bed aquifer is 5.13×10^{-6} m^2/s, based on single well response data from 14 tests on 10 wells (Figure 12). Values range from 7.08×10^{-5} m^2/s to 4.27×10^{-7} m^2/s. Calculated well yields range from 0.01 L/s in the extreme west of the project area to 0.54 L/s in the south central part of the study area. Although these values are extremes, they do indicate the trend. Lower transmissivities in the western part of the study area probably result from thinning and splitting of the coal, and from a decrease in fracture density and/or fracture aperture with the increase in depth in a westerly direction. On a local scale, the transmissivity of the Battle River Bed varies significantly over a relatively small area, a feature that is probably a reflection of the local degree of fracturing. For example, well development work on three sites 1 km apart (BR-72, 73, 74) revealed a noticeable difference in yield characteristics from site to site. Recovery times for these wells in the Battle River Bed, after having been blown dry with compressed air, required as little as a few minutes at site BR-72 and BR-74 (2 km east of BR-72), whereas at site BR-73 (1 km east of BR-72) full recovery took over 24 hours.

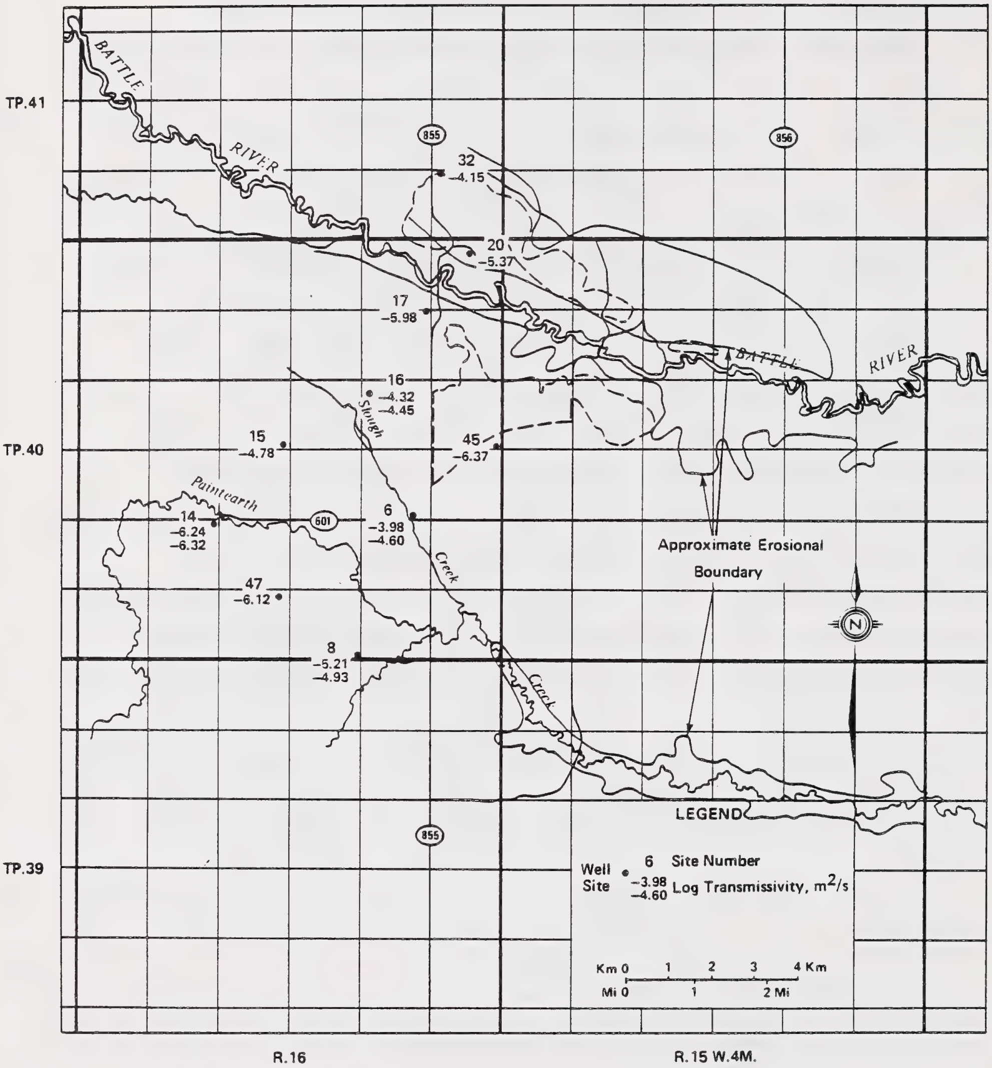


Figure 12. Log transmissivity (m^2/s) for the Battle River Bed aquifer.

5. POST-MINING WATER SUPPLY

Five aquifers were evaluated as potential post-mining water supply sources. Four of these are sandstone units located stratigraphically below the Battle River Bed, and are (from shallowest to deepest) the Delta Sandstone aquifer (Horseshoe Canyon Formation), Middle Sandstone aquifer (Bearpaw Formation), Deep Sandstone aquifer (Bearpaw Formation), and the Basal Sandstone aquifer (Bearpaw Formation). In addition, the Quaternary sediment fill in the valleys of the Battle River and Paintearth Creek was studied for its aquifer potential. As previously mentioned, the coal aquifers (Battle River Bed and Paintearth Bed) were considered for potential post-mining use in areas beyond the ultimate extent of mining, in areas where deeper aquifers are not suitable.

5.1 DELTA SANDSTONE AQUIFER

The Delta Sandstone aquifer is continuous over all of the study area except the valleys of Battle River and Paintearth Creek, where it has been eroded. It is generally 20 to 40 m below ground surface, the depth increasing to the west and southwest as a result of the increasing land surface elevation and the southwesterly dip of the bed. The Delta Sandstone is the thickest in the area that is to be mined, where it is as much as 22 m thick. Over most of the remaining area it is 12 to 15 m thick (Maslowski Schutze et al. 1985).

A thin shale layer separates the Delta Sandstone from the overlying Battle River Bed over most of the project area, as illustrated in Figure 13. This shale, which has a mean thickness of 1.12 m and ranges in thickness from 0.0 to 4.8 m, provides the only barrier to movement of water of degraded quality from the base of the mine spoil to the Delta Sandstone aquifer.

Water quality in the Delta Sandstone is generally good, with sodium-bicarbonate or sodium-chloride type water ranging from 947 to 3073 mg/L total dissolved solids (Figure 14). The water quality characteristics in terms of total dissolved solids and sulfate are illustrated by the cumulative frequency distribution

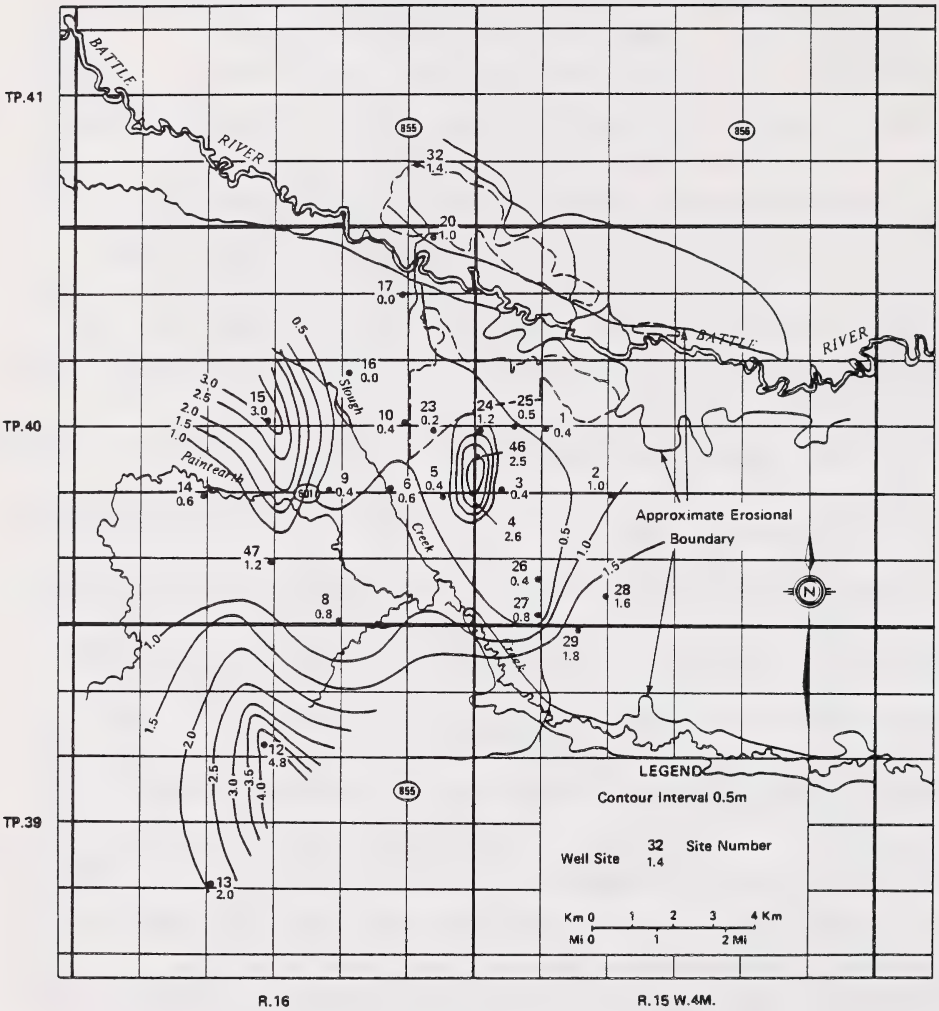


Figure 13. Thickness of shale between the Battle River Bed and the Delta Sandstone aquifer. Contour interval 0.5 m.

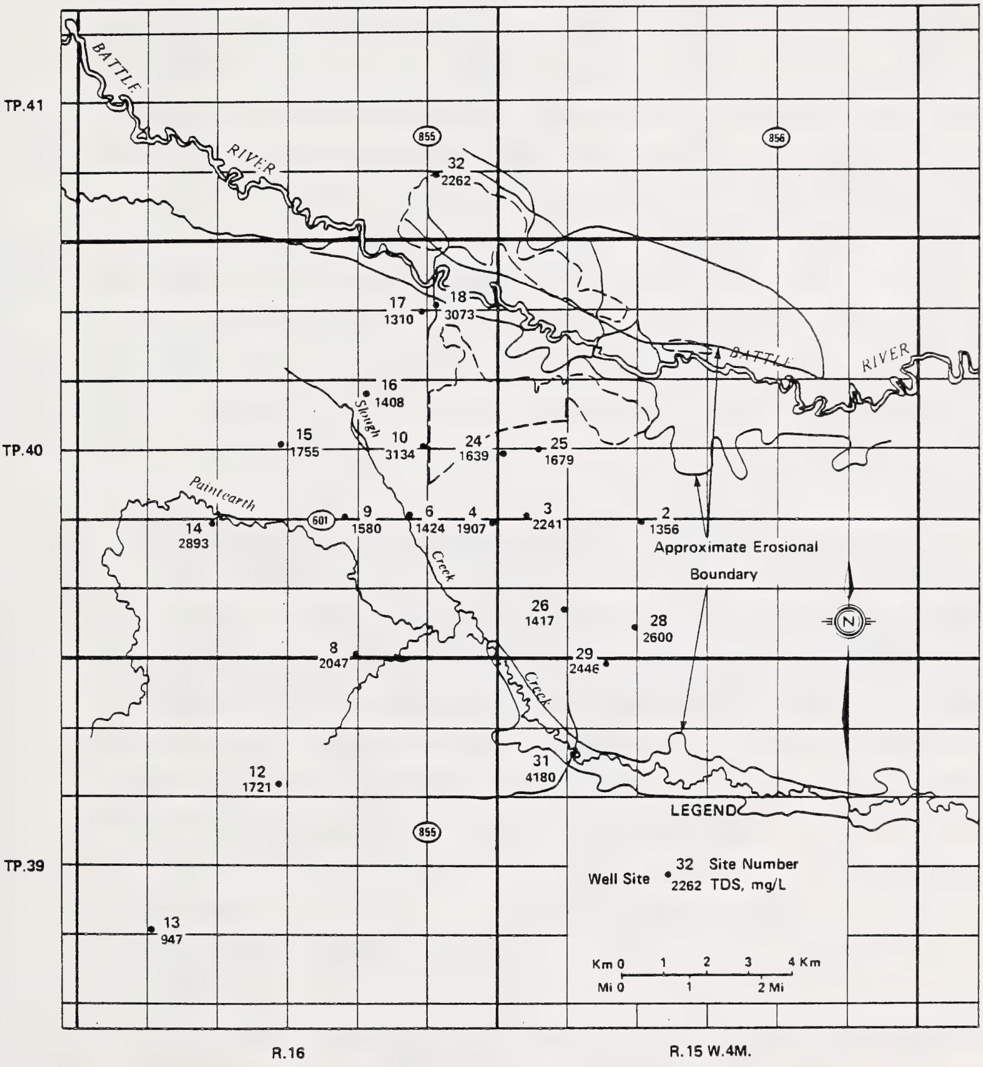


Figure 14. Total dissolved solids concentration (mg/L) in the Delta Sandstone aquifer.

curves of Figures 15 and 16 and summarized in Table 1. In Figure 15 it can be seen that the distribution of total dissolved solids in the Delta Sandstone is similar to that in both the coal aquifers and domestic well standards. Sixty-seven percent of samples from the Delta Sandstone are below 2000 mg/L TDS, compared to 65% and 59% for domestic wells and coal aquifers, respectively. Total dissolved solids in the Delta Sandstone tends to be somewhat lower than the coal aquifers over the entire range of concentrations, although the difference (10 to 15%) is only significant at concentrations above 1600 mg/L. At the lower end of the TDS range (below 1600 mg/L) the Delta Sandstone tends to be somewhat more saline than domestic wells; above 2000 mg/L the Delta Sandstone tends to be significantly less saline than the domestic wells standard.

The distribution of sulfate concentrations in the Delta Sandstone is significantly better than that in the domestic well standard, whereas compared to the coal aquifer standard there is little difference in sulfate concentrations as shown in Figure 16. Eighty-five percent of samples from the Delta Sandstone have less than 150 mg/L sulfate, versus 39% and 83% for domestic wells and coal aquifers, respectively. Overall, then, the water quality in the Delta Sandstone is comparable to or better than the water quality in the two standards, and from a water quality perspective, would act as an acceptable alternative water supply.

The mean transmissivity of the Delta Sandstone based on 13 tests from 8 wells is 2.7×10^{-7} m^2/s (Figure 17). The mean calculated well yield is 0.06 L/s which is below the yield of approximately 0.1 L/s considered to be the minimum for domestic supply purposes. At site BR-8, in the southwest part of the study area, the calculated yield of 0.37 L/s is adequate for domestic supply, and the water quality, at 2047 mg/L TDS, is better than 34% of existing domestic wells. However at this site only 0.8 m of shale lies between the Delta Sandstone and the base of the Battle River Bed. The potential for spoil groundwater to move through this shale bed, particularly through fractures, and contaminate the underlying

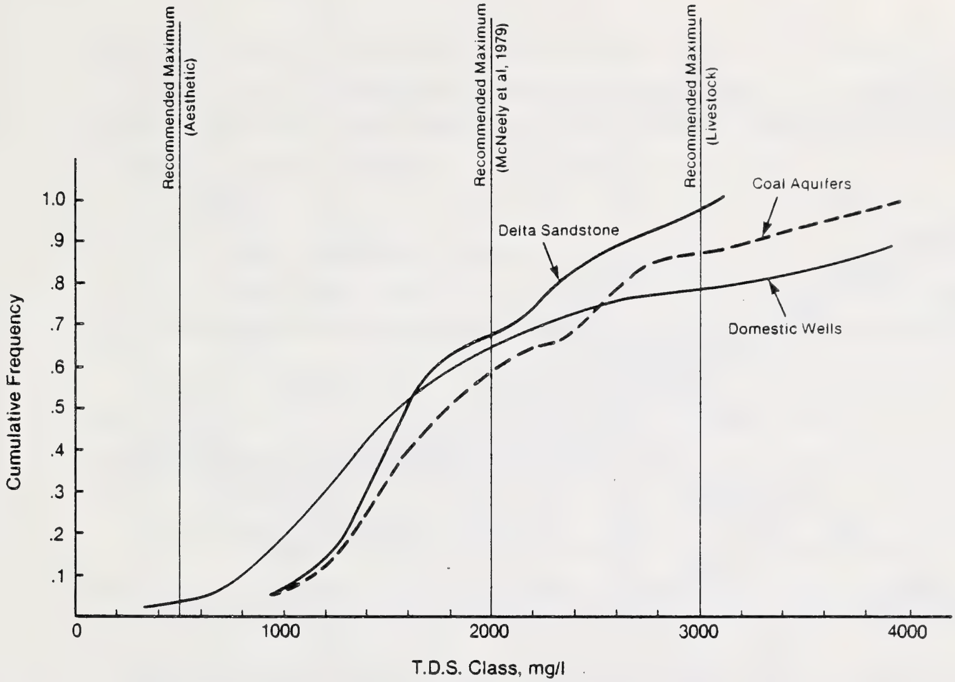


Figure 15. Cumulative frequency distribution for total dissolved solids (TDS) in the Delta Sandstone aquifer, compared to domestic water wells and coal aquifers.

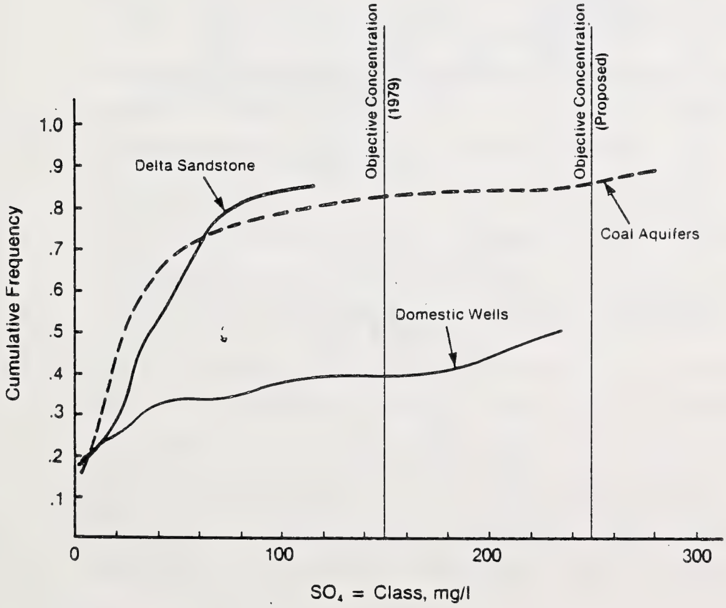


Figure 16. Cumulative frequency distribution for sulfate in the Delta Sandstone aquifer compared to domestic water wells and coal aquifers.

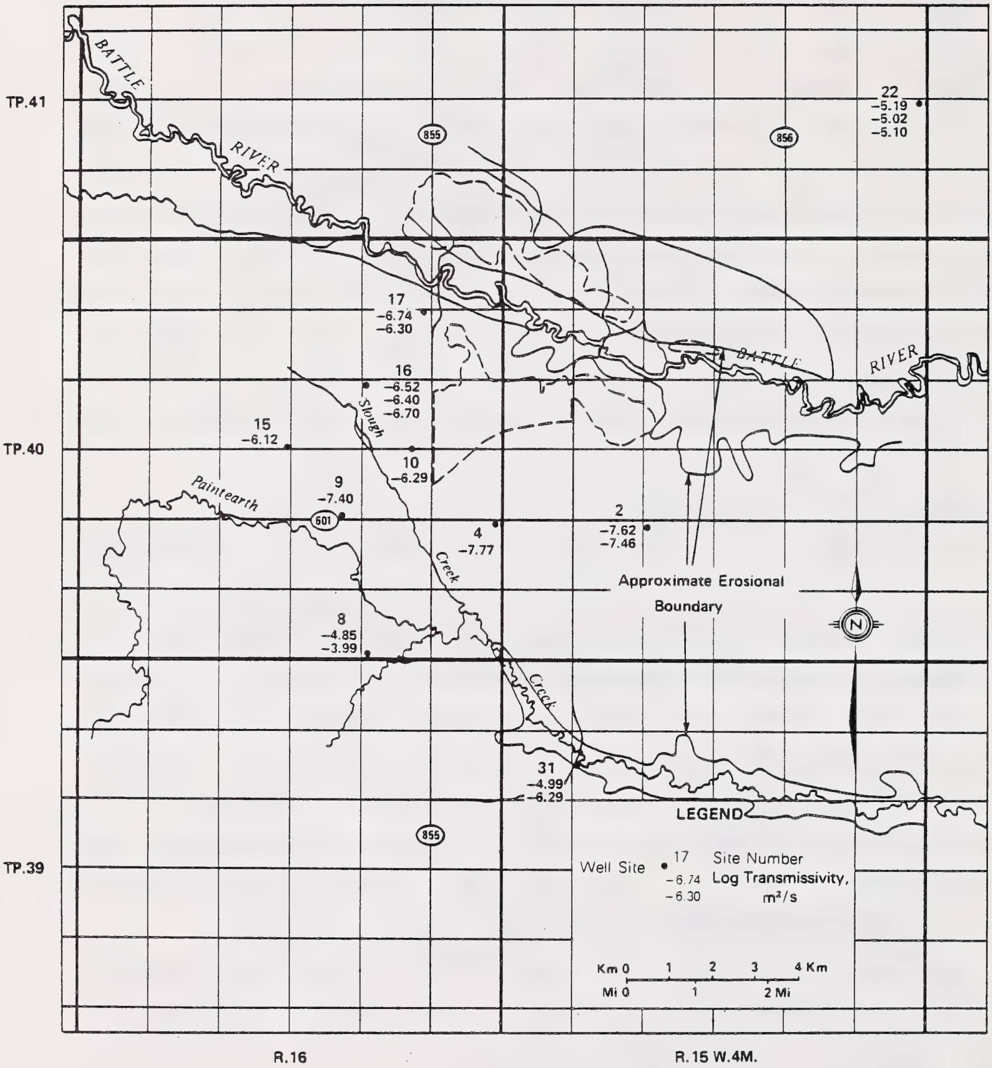


Figure 17. Log transmissivity (m^2/s) for PHRP piezometers in the Delta Sandstone aquifer.

Delta Sandstone is considered too great to accept this aquifer at site BR-8 as a long-term post-mining water supply. In general the Delta Sandstone is not considered a suitable post-mining water supply, primarily because of its low transmissivity.

5.2. DEEP SANDSTONE AQUIFER

The Deep Sandstone is continuous over the entire project area, although in the valleys of Paintearth Creek and the Battle River it has been eroded. This aquifer ranges in thickness from approximately 3 m in the east part of the study area to 20 m in the west. In the northeast, the Deep Sandstone is present 50 to 60 m below ground surface, increasing in depth to 100 m in the southwest.

The water in the Deep Sandstone is characterized by two distinctly different chemical compositions; one is a sodium-chloride type with high total dissolved solids, the second is a sodium-bicarbonate type with moderate total dissolved solids. Figure 18 illustrates the areal distribution of these two groups, and Table 1 summarizes their water quality characteristics. The first group, (West Group) which occurs in the western part of the study area, has a mean total dissolved solids concentration of 3072 mg/L, with a standard deviation of 304 mg/L. The second group (East Group), present in the eastern half of the project area and also north of Battle River, has a mean TDS concentration of 1828 mg/L, with a standard deviation of 504 mg/L. The distribution of total dissolved solids in the Deep Sandstone west samples (Figure 19) indicates that at concentrations below 3200 mg/L, the water quality in this group is significantly degraded with respect to either the domestic well standard or the pre-mining coal aquifers standard. For example, only 52% of the samples from the West Group of the Deep Sandstone have less than the 3000 mg/L TDS standard, compared to 78% of the samples from domestic wells and 86% from coal aquifers. Most samples from this group displayed lower sulfate concentrations than the domestic wells or coal aquifers, as illustrated in Figure 20. Overall,

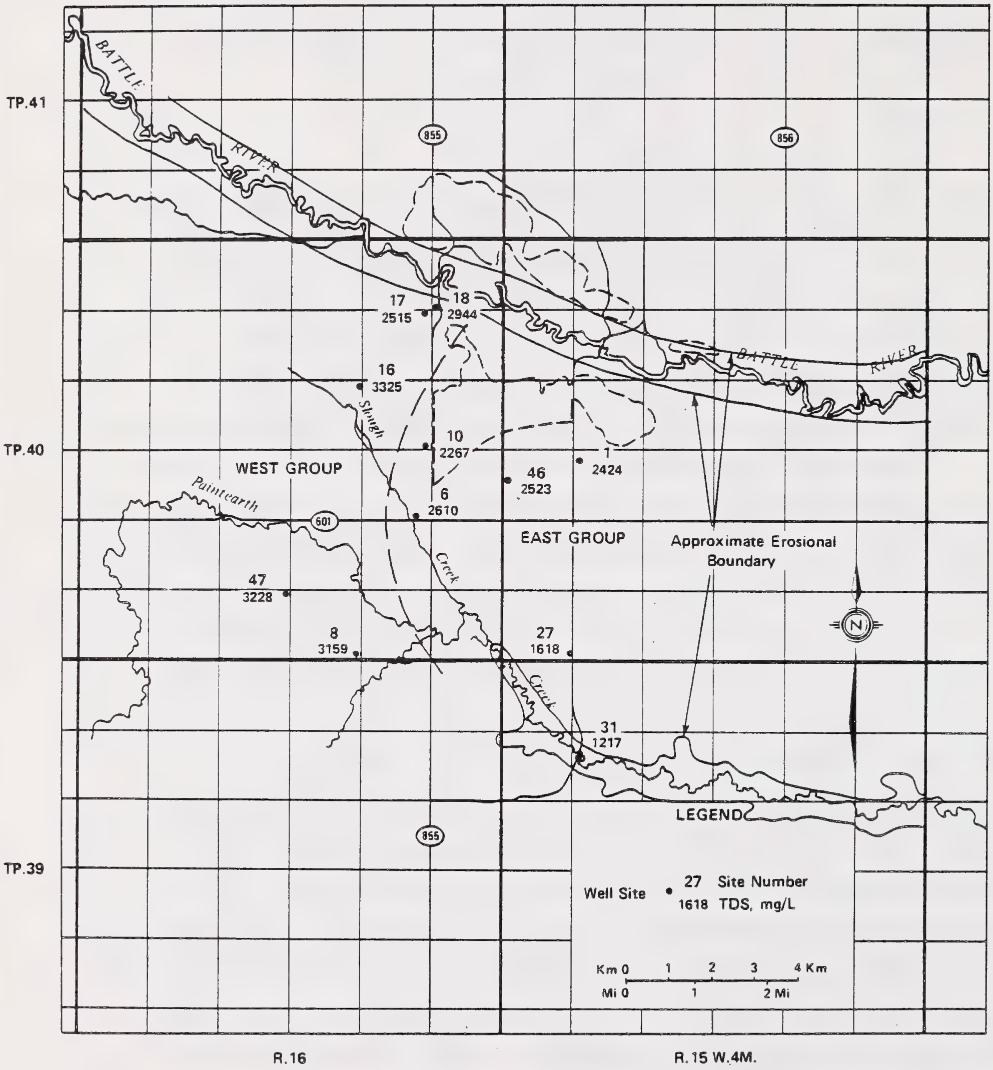


Figure 18. Total dissolved solids concentration (mg/L) in the Deep Sandstone aquifer for West Group (Na^+ - Cl^- type water east of Highway 855) and East Group ($NaHCO_3^-$ type water east of Highway 855).

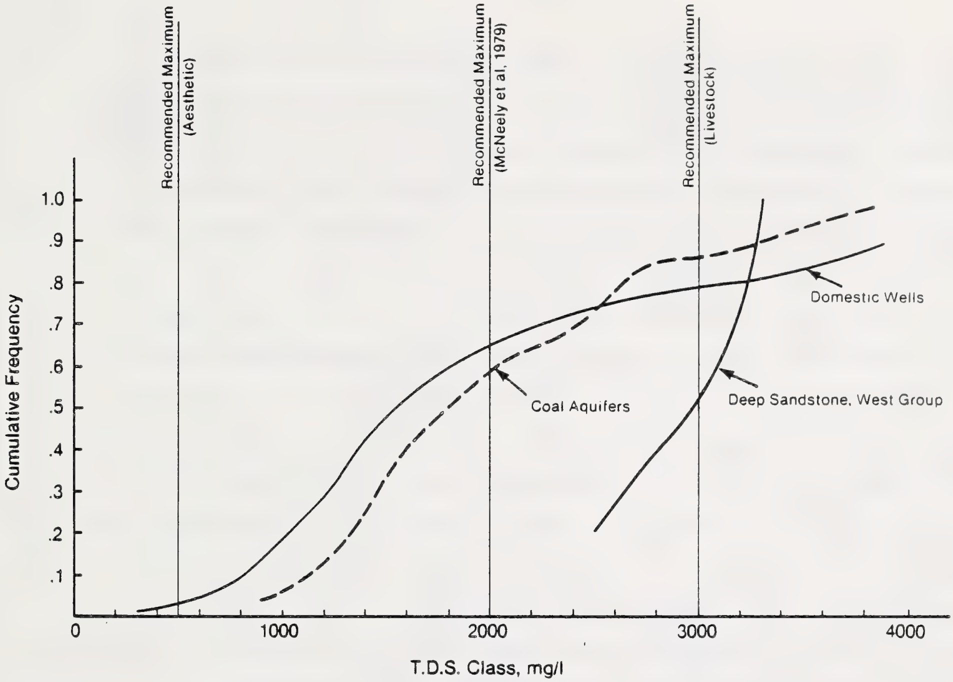


Figure 19. Cumulative frequency distribution for total dissolved solids (TDS) in the Deep Sandstone aquifer, West Group, compared to domestic water wells and coal aquifers.

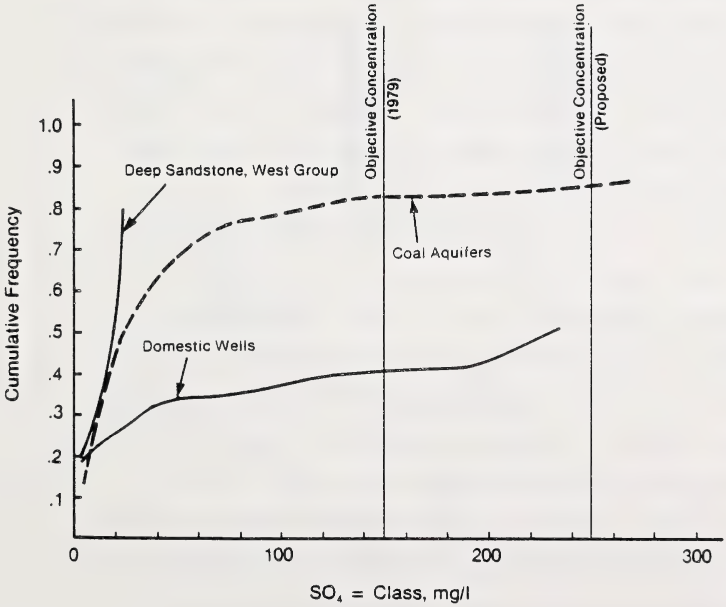


Figure 20. Cumulative frequency distribution for sulfate in the Deep Sandstone aquifer, West Group, compared to domestic water wells and coal aquifers.

however, the west portion of the Deep Sandstone aquifer is not considered to be an acceptable alternate water supply because of the high total dissolved solids concentrations which make it unsuitable for domestic consumption and marginally suitable for livestock consumption only near sites BR-17 and 18, immediately south of the Battle River, near the boundary with the East Group.

The distribution of total dissolved solids in the East Group of the Deep Sandstone aquifer (Figure 21) shows that 71% are below 2000 mg/L TDS, compared to 65% of the domestic well samples, and 59% of the coal aquifers samples. The fraction of the East Group samples above 2000 mg/L TDS (30%) tends to be significantly less saline than either the domestic well or coal aquifer standards. The distribution of sulfate in the Deep Sandstone East Group wells (Figure 22) shows that sulfate concentrations in this group are similar to, though somewhat higher than, the coal aquifer standard, but significantly better than the domestic well standard.

Water from the Deep Sandstone in the western part of the study area has mean concentrations of sulfate, sulfide and iron that are 52.6, 0.014, and 0.044 mg/L, respectively. The water from the eastern part of the study area has sulfate, sulfide and iron mean concentrations of 108, 0.019, and 0.15 mg/L, respectively. In each case the mean concentrations of these three species are less than maximum recommended concentrations for drinking water.

Overall the water quality from the East Group of the Deep Sandstone aquifer is considered to be acceptable as an alternative to existing aquifers, for both domestic and livestock consumption.

The difference in water quality between the two groups of the Deep Sandstone aquifer can be traced to their respective sources of recharge. The lower salinity, sodium-bicarbonate type waters of the East Group originate as recharge through the valley fill sediments of Paintearth Creek, which cut through the Deep Sandstone in the southeastern part of the study area. This local source of recharge and corresponding relatively short flow path account for the type of water found in the Deep Sandstone in the eastern part of the

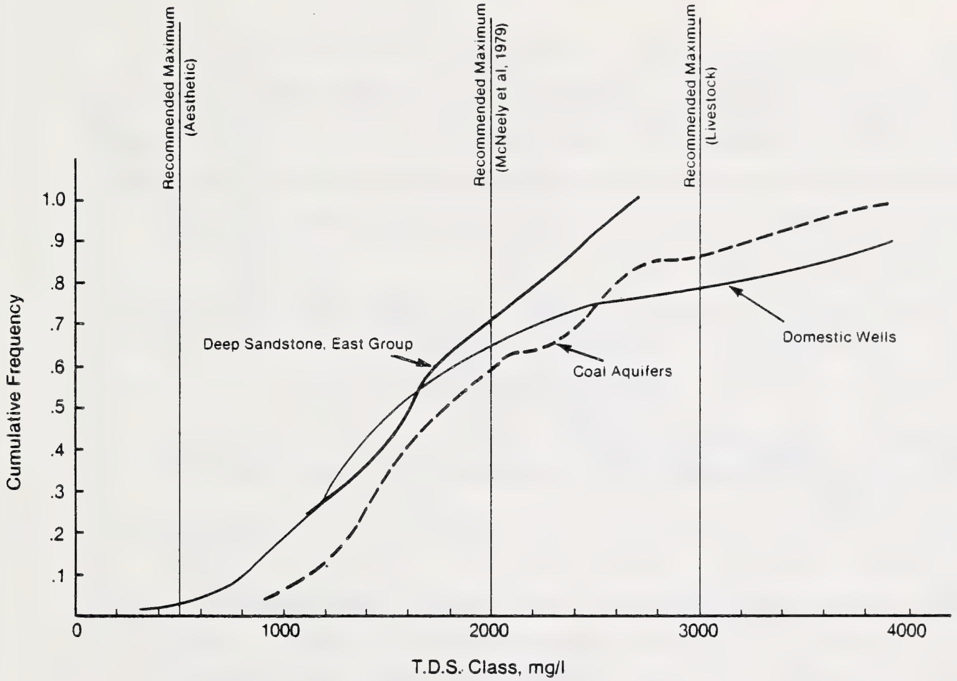


Figure 21. Cumulative frequency distribution for total dissolved in solids (TDS) in the Deep Sandstone aquifer, East Group, compared to domestic water wells and coal aquifers.

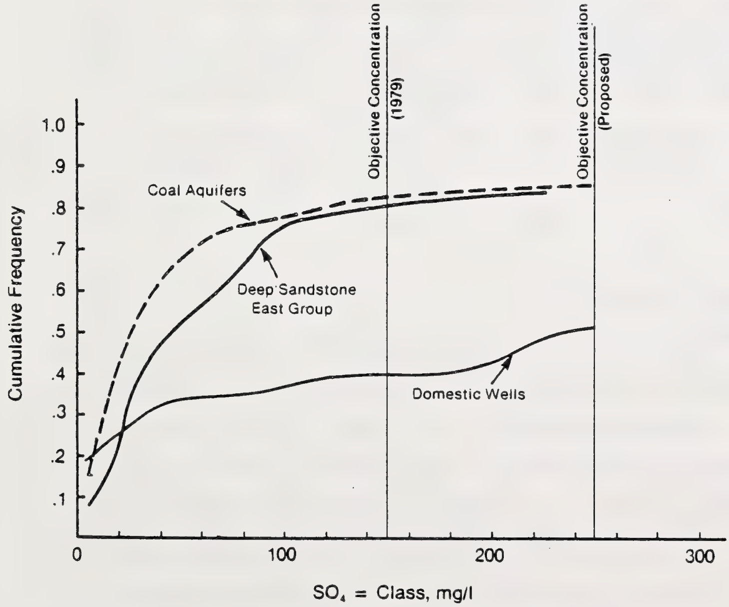


Figure 22. Cumulative frequency distribution for sulfate in the Deep Sandstone aquifer, East Group, compared to domestic water wells and coal aquifers.

study area. In the western part of the study area the source of recharge is more distant, and consequently the longer flow path and residence time has provided the time needed for saline water from the marine confining beds to diffuse into the Deep Sandstone, giving rise to the higher salinity, sodium-chloride type water that is characteristic of the west group.

The transmissivity of the Deep Sandstone aquifer has been determined from single-well response tests of 13 piezometers, and one pumping test (Figure 23). The twenty-four-hour pumping test with one observation well plus a step drawdown test were conducted at site BR-10. The value of transmissivity determined from this test is 1.09×10^{-5} m^2/s; storativity is 3.06×10^{-5}; and safe yield is 0.23 L/s. The mean transmissivity of the Deep Sandstone is 8.32×10^{-6} m^2/s with a log standard deviation of 0.74. The mean long-term well yield is 0.496 L/s, which is more than adequate to meet domestic supply needs. At all sites except BR-8 and BR-47 in the southwest part of the study area the calculated well yields are above the acceptable minimum.

In summary, then, the Deep Sandstone aquifer is an acceptable post-mining water supply, both in terms of water quantity and quality, in the eastern part of the study area. In the western part of the study area, yields from the Deep Sandstone aquifer are adequate, but it is not a suitable post-mining water supply because of its high total dissolved solids concentrations.

5.3. MIDDLE SANDSTONE AQUIFER

A possible alternative to the Deep Sandstone aquifer west of Highway 855, whose waters are unsatisfactory because of its high salinity, is the Middle Sandstone aquifer. This unit is continuous over the project area except where eroded in the Battle River Valley and in the Paintearth Creek Valley. The Middle Sandstone ranges from 10 to 20 m in thickness, and is more fine grained in the eastern part of the project area. It ranges in depth from 50 to 80 m below ground surface, generally increasing in depth to the southwest and west.

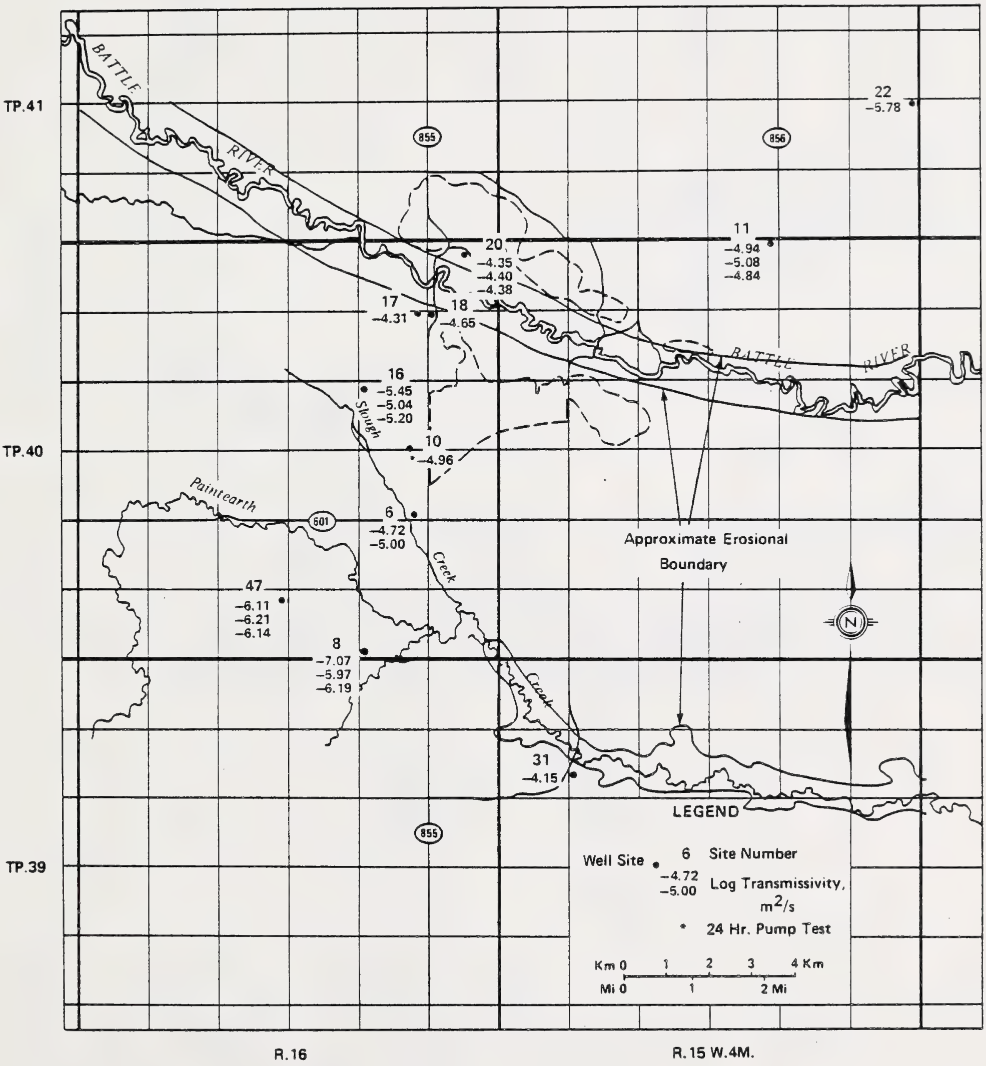


Figure 23. Log transmissivity values (m^2/s) for the Deep Sandstone. *Transmissivity at site BR-10 determined from 24-hour pumping test.

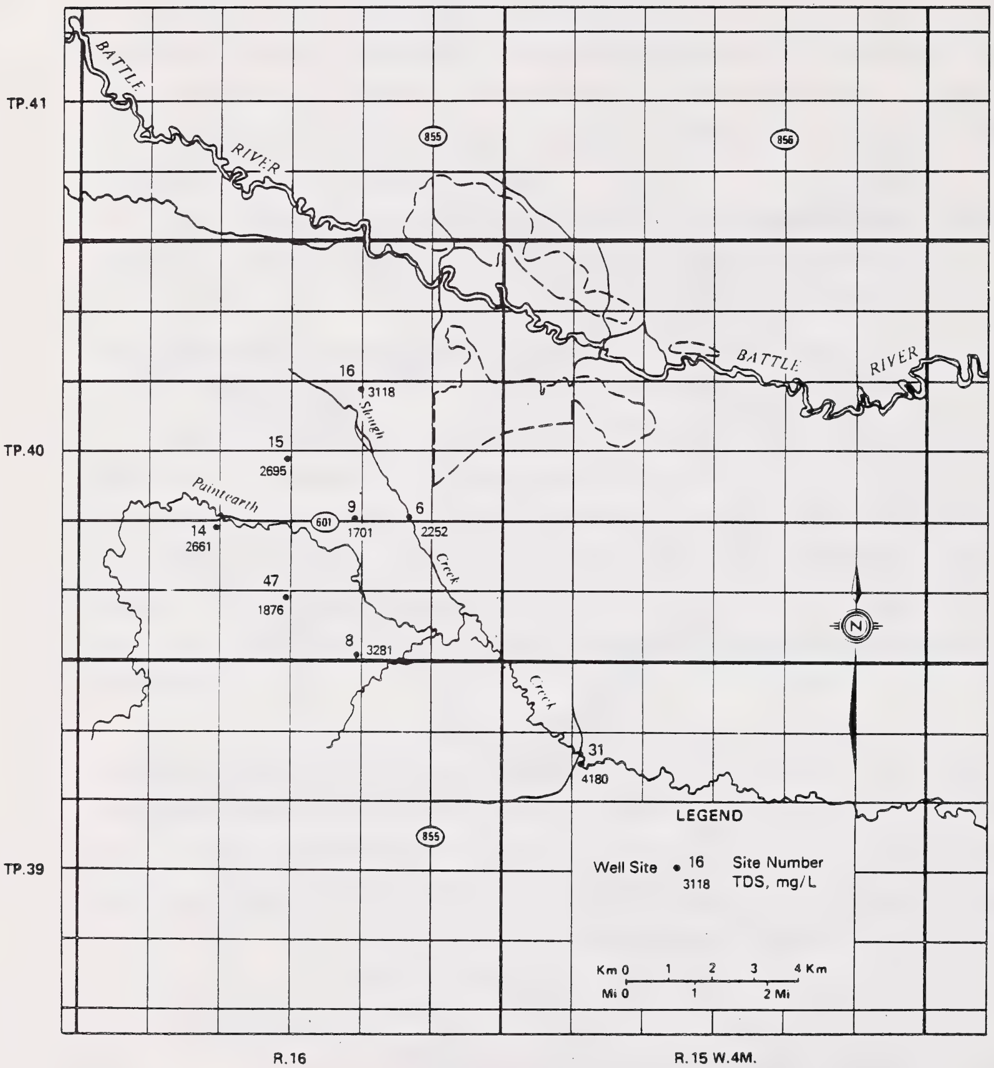


Figure 24. Concentration of total dissolved solids (mg/L) in the Middle Sandstone aquifer.

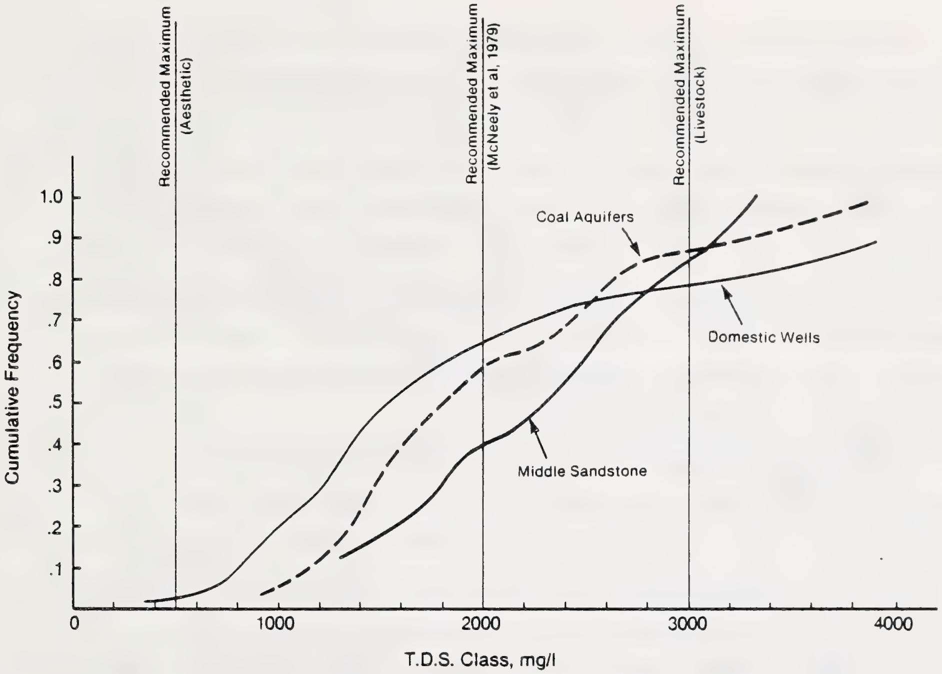


Figure 25. Cumulative frequency distribution for total dissolved solids (TDS) in the Middle Sandstone aquifer, compared to domestic water wells and coal aquifers.

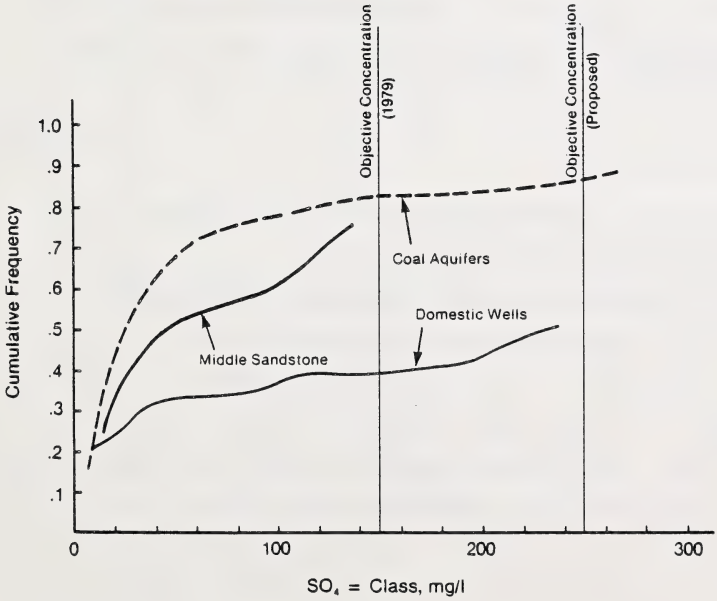


Figure 26. Cumulative frequency distribution for sulfate in the Middle Sandstone aquifer, compared to domestic water wells and coal aquifers.

Water in the Middle Sandstone aquifer is primarily of the sodium-chloride type, with a mean total dissolved solids concentration of 2385 mg/L (Figure 24). The distribution of total dissolved solids illustrated in Figure 25 shows that 40% of the samples have less than 2000 mg/L TDS, compared to 65% and 59% of domestic well and coal aquifer samples, respectively (Table 1). The distribution of sulfate in the Middle Sandstone (Figure 26) indicates that the Middle Sandstone has sulfate levels that are intermediate between the two standards, higher than the coal aquifers but lower than the domestic wells.

The mean transmissivity of the Middle Sandstone, as determined from 18 single well response tests on 8 wells is 8.3×10^{-7} m^2/s (Figure 27). Calculated well yields ranged from 1.7×10^{-4} L/s to 0.27 L/s. Only 1 well, located at site BR-47 in the southwest part of the study area, produced water at a rate suitable for domestic supply purposes (equal to or greater than 0.1 L/s). The total dissolved solids concentration of 1876 mg/L at site BR-47 is lower than 40% of the domestic well samples, and lower than 50% of the coal aquifer samples. Consequently the Middle Sandstone is considered to be an acceptable alternate water supply, both in terms of water quality and quantity, only in the vicinity of site BR-47.

5.4. BASAL SANDSTONE AQUIFER

The Basal Sandstone aquifer was also studied as a possible alternate water supply source. The Basal Sandstone is stratigraphically below the Deep Sandstone, separated from it by approximately 5 to 10 m of interbedded shale and siltstone.

The mean transmissivity of the Basal Sandstone is 1.70×10^{-6} m^2/s, based on 7 single well response tests on 3 piezometers (Figure 28). The average calculated well yield for these 3 wells ranged from 0.03 L/s at sites BR-8 and BR-22 to 0.17 L/s at site BR-15.

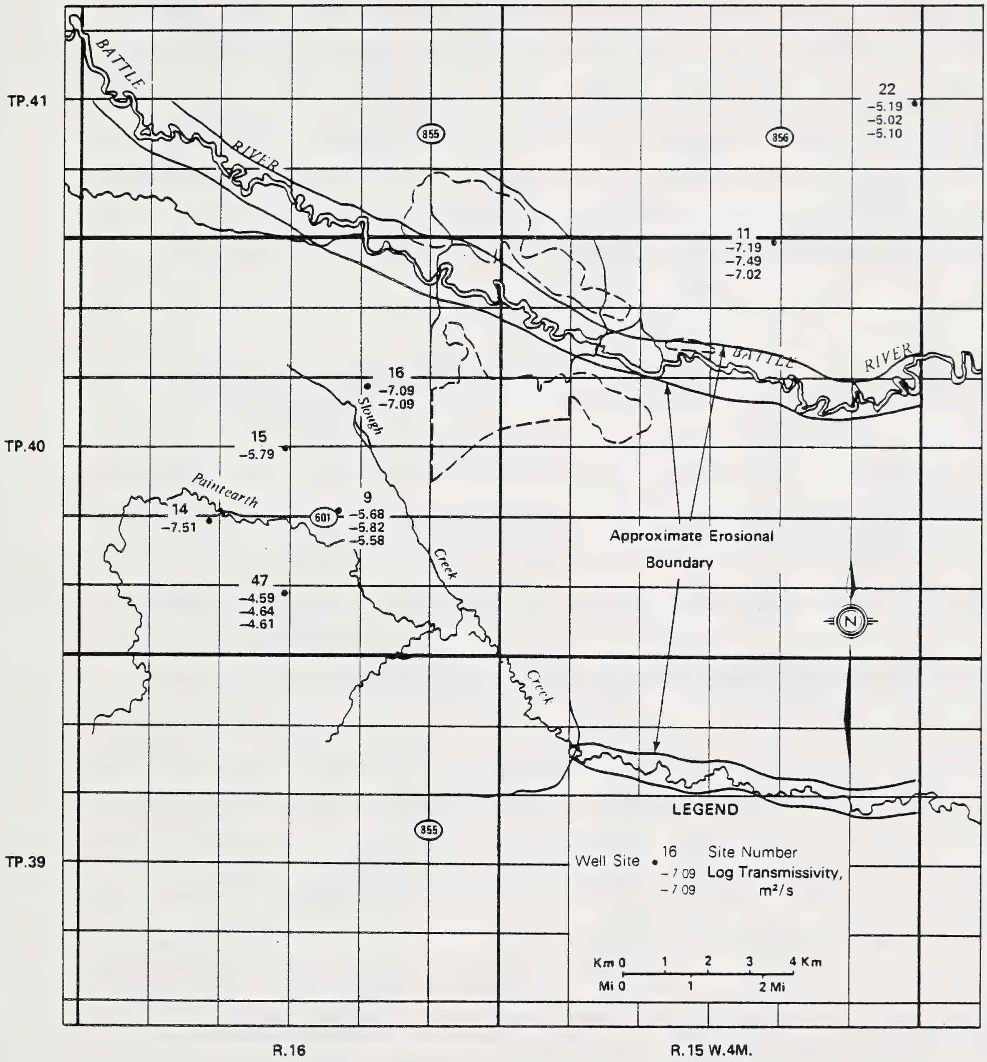


Figure 27. Log transmissivity values (m^2/s) for the Middle Sandstone.

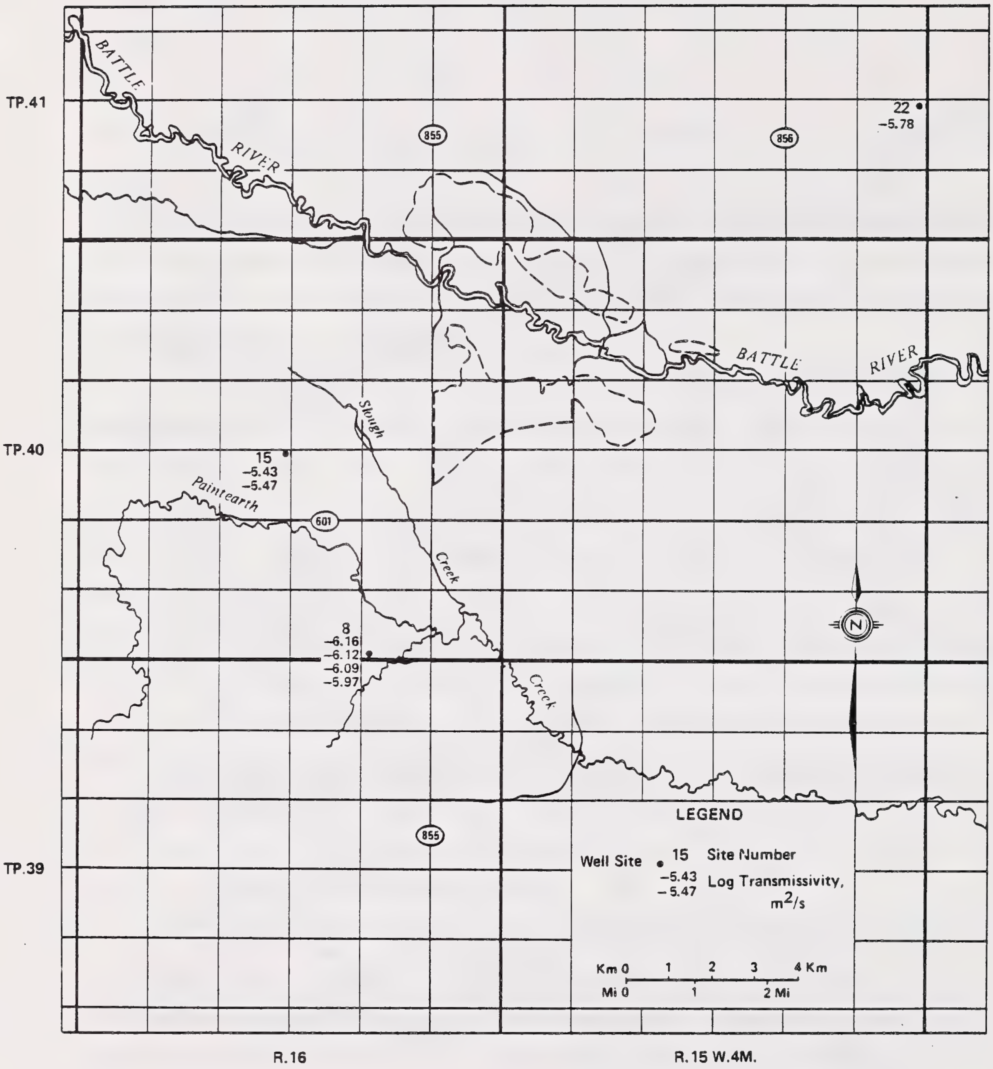


Figure 28. Log transmissivity values (m^2/s) for the Basal Sandstone.

The water quality of the Basal Sandstone parallels that in the Deep Sandstone. Water from the Basal Sandstone is somewhat higher in total dissolved solids than the Deep Sandstone, although similar in chemical makeup. The Basal Sandstone therefore does not appear to be a suitable alternative to the Deep Sandstone in the western part of the study area, as its water tends to be more saline than water in the Deep Sandstone. In the eastern part of the study area, the Basal Sandstone aquifer may be suitable for supplementing yields from the Deep Sandstone aquifer.

5.5 VALLEY FILL AQUIFER

The valley fill aquifers in the project area are comprised of Quaternary age sediment deposited in the valleys of Battle River and Paintearth Creek. This sediment consists primarily of silt and clay with a minor sand component. No gravel was encountered in test drilling at either site BR-19 in the Battle River fill or BR-31 in the Paintearth Creek fill.

In the Battle River fill the average transmissivity determined from 2 tests on 1 piezometer at site BR-19 is 3.5×10^{-6} m^2/s, with corresponding average well yield of 0.12 L/s. At site BR-31, the fill sediment of Paintearth Creek has a transmissivity of 3.5×10^{-5} m^2/s, based on 1 single well response test, with a corresponding yield of 0.08 L/s. The low yield recorded for the Paintearth Creek fill is in large part an artifact of the shallow depth of the piezometer, which resulted in an available drawdown of only 2 or 3 m. A well installed near the base of the fill, at a depth of 25 m, would have significantly higher available drawdown, and would be capable of producing an adequate amount of water for domestic use.

The mean total dissolved solids concentration for water in the valley fill is 1879 mg/L, with a standard deviation of 687. The mean value for sulfate is 114 mg/L, with a standard deviation of 74. The mean concentration of sulfide and iron are 0.017 and 0.935 mg/L, respectively. All values are within maximum allowable limits, except for iron which is more than three times the maximum. The concentration of iron is above the allowable maximum only in the Battle River Valley fill, whereas the concentration of iron in Paintearth Creek Valley fill is within allowable limits.

6. SUMMARY AND CONCLUSIONS

In Figure 29 the water quality characteristics of both pre-mining aquifers and potential post-mining aquifers are summarized graphically. Table 2 is a summary of water quality and quantity for potential post-mining aquifers. The shallow coal aquifers (Paintearth Bed and Battle River Bed) in the Battle River Project area are a major source of water for domestic use at present. Of five potential post-mining aquifers, located stratigraphically below the coal, the Delta Sandstone and Middle Sandstone aquifers are of limited use, primarily because of inadequate transmissivity. The valley fill aquifers of the Battle River and Paintearth Creek are suitable for exploitation by small domestic wells, but are of limited areal extent.

The main limitation of the deeper sandstone aquifers of the Bearpaw Formation is the occurrence of relatively high salinity sodium-chloride type water in areas beyond the influence of local recharge through valley fill sediments (Table 2). Over most of the Battle River Project area the Deep Sandstone aquifer has the potential to serve as a post-mining groundwater supply as shown in Figure 30. However, in the portion of the study area that is west of a line that corresponds approximately to Highway 855 (Figure 30), water from the Deep Sandstone aquifer is too saline for domestic use (without significant treatment). For much of this western part of the area there is no suitable post-mining groundwater supply below the zone of mineable coal. Within the limits of proposed mining for this area no viable post-mining groundwater supply has been identified. Beyond the limits of proposed mining in this area the coal aquifers are the principal candidates for post-mining groundwater supply, but maybe subject to potential dewatering during the mining period, and contamination by the migration of spoil groundwater beyond mine boundaries after mining and reclamation (Trudell and Moran 1984).

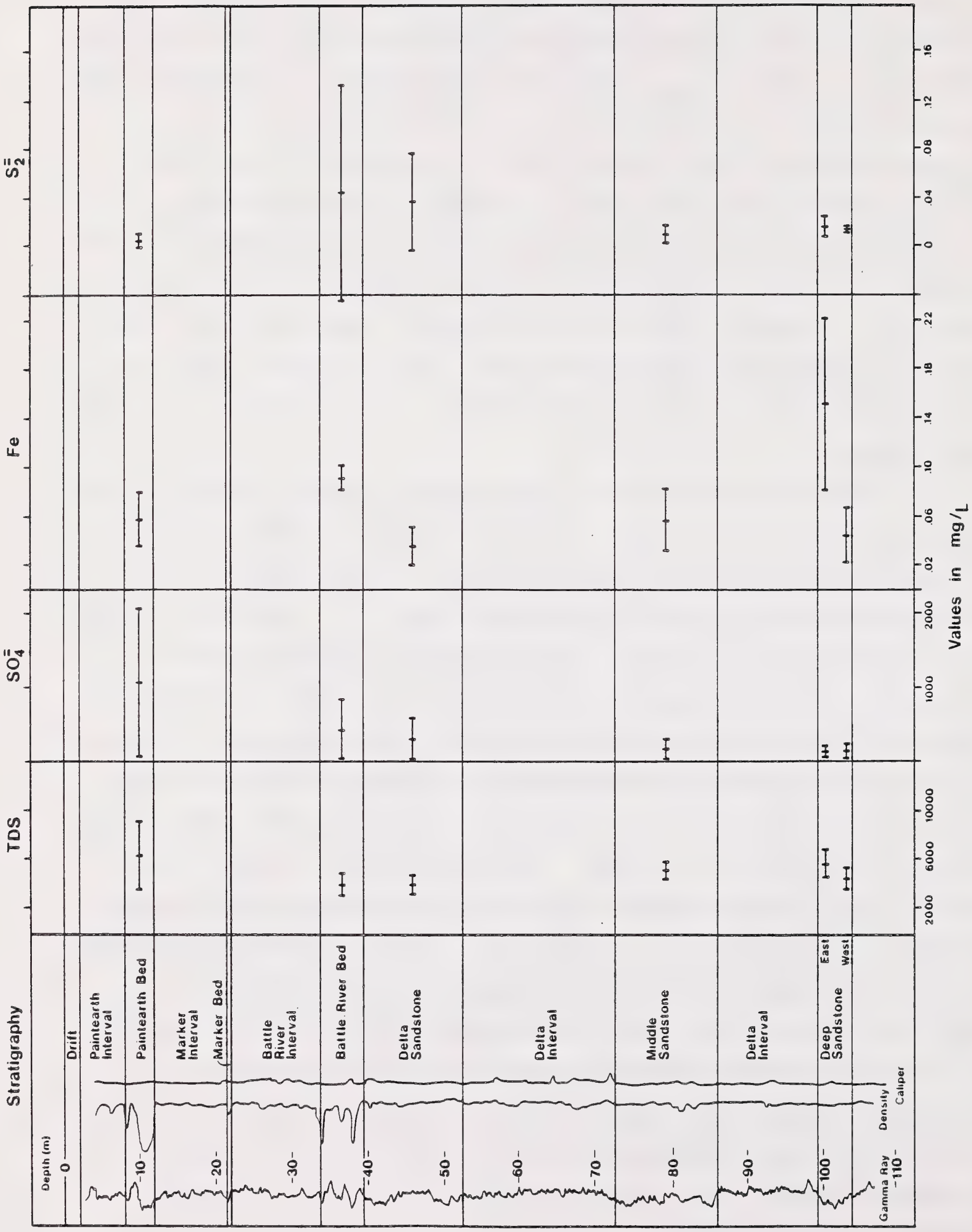


Figure 29. Standard deviation (spread of bars), and mean (centre of bar) for total dissolved solids, sulfate, iron, and sulfide, by aquifer, from PHRP piezometers.

Table 2. Summary of post-mining groundwater sources, Battle River study area.

Area	Aquifer	Quantity	Quality	Limiting Factors, Comments
West Area*	Paintearth Bed	Adequate	TDS 1 200 to 3 600 mg/L $SO_4^=$ 9 to 1 300 mg/L	Generally acceptable in areas more than 1.6 km west of mine permit boundary
	Middle Sandstone	Generally inadequate except near NE27-40-16-W4	TDS 1 700 to 3 300 mg/L $SO_4^=$ low	Acceptable only near NE27-40-16-W4 Elsewhere insufficient yield
	Deep Sandstone	Generally adequate	TDS 3 100 to 34 00 mg/L $SO_4^=$ low	TDS excessive for human consumptions marginal for livestock
East Area**	Battle River Bed	Adequate	TDS 1 900 to 3 500 mg/L $SO_4^=$ low	Generally acceptable in area more than 1.6 km east of mine permit boundary
	Deep Sandstone	Adequate	TDS 1 600 to 2 900 mg/L $SO_4^=$ low	Generaly suitable for exploitation; also suitable north of Battle River
Battle River Valley	Valley Fill	Adequate	TDS 1 900 mg/L Low $SO_4^=$ High iron	Acceptable with treatment for iron; limited areal extent

* Approximately west of Highway 855

** Approximately east of Highway 855

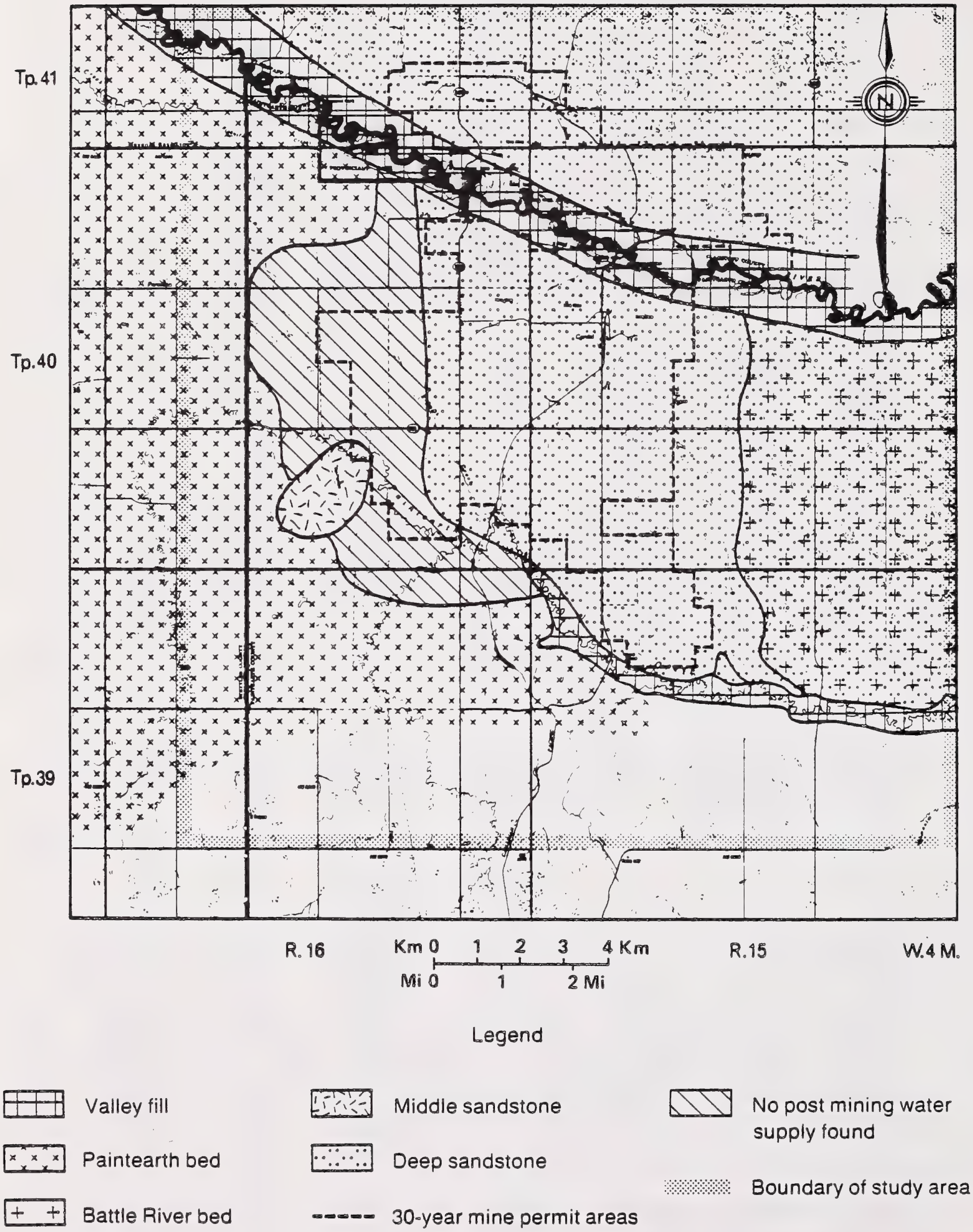


Figure 30. Overview map showing the composite post-mining water supply potential of the Battle River Project area.

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